Lewis County Critical Areas Ordinance Update

Best Available Science Review and Recommendations for Code Update

Geological Hazards

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ACRONYMS

B.P.	before present
BAS	Best Available Science
BMP's	Best Management Practices
CAO	Critical Areas Ordinance
CARAs	Critical aquifer recharge areas
CFHMP	Comprehensive Flood Hazard Management Plan
CMZ	channel migration zone
CTED	Community Trade and Economic Development
CVO	Cascade Volcano Observatory
GMA	Growth Management Act
HCAs	habitat conservation areas
LWD	large woody debris
NGPEs	Native Growth Protection Easements
NRCS	Natural Resources Conservation Service
PNSN	Pacific Northwest Seismograph Network
SMP	Shoreline Master Program
SPNSN	Staff of the Pacific Northwest Seismograph Network
SWPPP	Stormwater Pollution Prevention Plan
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WADNR	Washington Department of Natural Resources
WRIA	Water Resource Inventory Areas

1. INTRODUCTION

In 1995, the Washington State Legislature amended the Growth Management Act (GMA) to require that local governments include Best Available Science (BAS) in designating and protecting critical areas (RCW § 36.70A.172(1)). In 2000, the State's Office of Community Trade and Economic Development (CTED) adopted procedural criteria to implement these changes to the GMA and provided guidance for identifying BAS. The rule makers concluded that identifying and describing functions and values and estimating the types and likely magnitudes of adverse impacts were scientific activities. Thus, RCW 36.70A.172(1) and the implementing regulations require the substantive inclusion of BAS in developing critical area policies and regulations.

This document summarizes BAS for Lewis County critical areas and provides recommendations for updating the County's Critical Areas Ordinance (CAO).

Critical areas as defined by RCW 36.70A.050, include the following:

- Geologically hazardous areas
- Frequently flooded areas
- Critical aquifer recharge areas (CARAs)
- Wetlands (both freshwater and estuarine)
- Fish and wildlife habitat conservation areas (HCAs)

1.1 REPORT BACKGROUND AND PURPOSE

The information contained within this document is a summary of scientific studies related to designating and protecting geologically hazardous areas. The information provides a basis for recommended changes and additions to the Lewis County CAO. It is not intended to provide an exhaustive summary of all science available. The information reviewed is pertinent to Lewis County, applicable to the types of geologically hazardous areas present, and believed to be the best available scientific information.

BAS[1] means current scientific information derived from research, monitoring, inventory, survey, modeling, assessment, synthesis, and expert opinion that are:

- Logical and reasonable.
- Based on quantitative analysis.
- Peer reviewed.
- Used in the appropriate context.
- Based on accepted methods.
- Well referenced.

This report is focused on geologically hazardous areas; however, the information presented for one critical area often overlaps, complements, or is applicable to another type of critical area because these areas function as integrated components of the ecosystem. The reports summarize the information and issues that the County is required to consider within its process for updating policies and regulations to protect the functions and values of critical areas (RCW 36.70A.172.1).

[1] Washington Administrative Code (WAC) 365-195-900 through 925.

In some instances the GMA and its regulations constrain the choice of science that can be used to designate or protect a particular resource (e.g., local governments are required to use the definition of wetlands [RCW 36.70A.030.2]). In other cases, there may a range of options that are supported by science (e.g., wetland buffer widths necessary to protect functions).

The provisions of the Washington Administrative Code (WAC) that provide minimum guidelines to classify critical areas give the following definition:

> **Geologically hazardous areas** are areas that because of their susceptibility to erosion, sliding, earthquake, or other geological events, ***are not suited to*** siting commercial, residential, or industrial development consistent with public health or safety concerns. (WAC 365-190-030(8)) (emphasis added)

WAC 365-190-080(4)(a) provides additional guidance as follows (emphasis and bullets added):

> **Geologically hazardous areas** include areas susceptible to
>
> - erosion,
> - sliding,
> - earthquake, or
> - other geological events.

They pose a threat to the health and safety of citizens when incompatible commercial, residential, or industrial development is sited in areas of significant hazard.

- Some geological hazards can be reduced or mitigated by engineering, design, or modified construction or mining practices so that risks to health and safety are acceptable.
- When technology cannot reduce risks to acceptable levels, building in geologically hazardous areas is best avoided.

This distinction should be considered by counties and cities that do not now classify geological hazards as they develop their classification scheme.

WAC 365-190-080(4)(b) states (emphasis added):

Counties and cities should classify geologically hazardous area as either:

(i) Known or suspected risk;

(ii) No risk;

(iii) Risk unknown - data are not available to determine the presence or absence of a geological hazard.

Growth Management Hearings Board decisions on geologically hazardous areas are relatively limited. The decision that appears most relevant is the following:

> *The more troubling question is what land use regulations are required, once a hazard is acknowledged. The County reasons that the only remaining question – reasonable occupancy limits [for a covered assembly in the lahar zone] – is a policy choice based on weighing risks. In the County's calculus, the low frequency of lahar events, the likelihood of early warning, and the opportunity for evacuation must be weighed against the economic opportunity presented by new tourist facilities. The Board agrees with Pierce County that landuse policy and responsibility with respect to Mount Rainier Case II lahars – "low probability, high consequence" events – is within the discretion of the*

elected officials; they bear the burden of deciding "How many people is it okay to sacrifice."[Tahoma/Puget Sound, 05304c, FDO, at 23-25.]

Throughout this discussion of geologically hazardous areas, risk is assessed in accordance with the criteria in WAC 365-190-080(4)(b):

(i) Known or suspected risk;

(ii) No risk;

(iii) Risk unknown - data are not available to determine the presence or absence of a geological hazard.

Options are presented in terms of trade-offs in exposing human populations to risk.

1.2 RELATIONSHIP TO OTHER PLANNING EFFORTS

The recommendations derived from the BAS review will be used as the basis for revising the County's development regulations and Comprehensive Plan elements that pertain to critical areas. The County is required to protect integrate critical areas. In addition to the provision of Lewis County Code Chapter 17.35 relating to Critical Areas and Chapter 15.35 relating to Flood Damage Prevention, this may include revisions to protection into zoning regulations, clearing and grading provisions, stormwater management requirements, subdivisions regulations and other applicable plans and policies.

The County is also required to integrate the CAO provisions with its Shoreline Master Program (SMP), which must be updated by the end of 2012in 2005. This update of the CAO provisions is not intended to comply with Shoreline Management Act guidelines. In the future, when the Shoreline Master Program is updated, To comply with House Bill 1933, SMP shoreline regulations pertaining to critical areas must be as protective or more protective of functions and values as the CAO regulations themselves applicable in the rest of the county (RCW 90.58.090(4).

1.3 COUNTY SETTING

Lewis County, the largest county in Washington State, encompasses 2,452 square miles in the southwest portion of the state. The crest of the Cascade Mountains forms the eastern boundary of the county, and is abutted to the east by Yakima County and the Yakima Indian Reservation. It is bounded by Thurston and Pierce Counties to the north, Pacific County to the west, and Wahkiakum, Cowlitz, and Skamania Counties to the south.

The County includes the cities of Centralia, Chehalis, Winlock, Napavine, Morton, Mossyrock, Pe Ell, Toledo, and Vader. Approximately 60 percent of the County's population of 71,000 live in unincorporated areas outside of cities. Lewis County's two largest cities, Centralia and Chehalis, are located in the western portion of the County and have a population of about 15,350 and 7,000, respectively.

Federal lands within Lewis County include portions of the Snoqualmie National Forest, the Gifford Pinchot National Forest, the Mount St. Helens National Volcanic Monument, Mt. Rainier National Park, and the Goat Rock Wilderness area. Reservation and trust lands of the Chehalis Indian Nation are located within the County.

According to the Lewis County Comprehensive Plan, approximately 74 percent of land within the county is committed to federal, state, and private resource land uses. Most of this land is primarily used for mineral, agricultural, forestry, and recreational uses. Only 1 percent of the resource land lies within urban areas. Over 98 percent of Lewis County is classified as open space or remote rural areas and less than 2 percent is available for urban or more intense rural development.

Lewis County contains portions of the following Water Resource Inventory Areas (WRIA): WRIA 23 (Upper Chehalis), WRIA 26 (Cowlitz), WRIA 11 (Nisqually), and WRIA 13 (Deschutes). The Nisqually, Chehalis, and Cowlitz rivers are the three major rivers in the area.

The County includes the upper Chehalis Valley, much of the Cowlitz River Drainage and numerous other creeks draining the foothills and mountains. The Cowlitz River flows from the Cowlitz Glacier. The valley extends west about 80 miles from the rugged glacially modified mountains to the southwest part of Lewis County with bottom lands, terraces, and broad plains. The Chehalis River Valley is in the southern part of the Puget Trough and includes a broad well developed flood plain and low terraces surrounded by dissected uplands of low to moderate relief with rounded ridges (Evans and Fibich 1987). The Nisqually River is fed by the Nisqually Glacier on Mount Rainier and follows part of the northern boundary of Lewis County. Small headwater portions of the Deschutes, Elochoman, Grays, and other rivers and creeks are found around the edges of Lewis County.

Tectonic and volcanic activity, glaciation, and rivers have shaped the landforms that make up Lewis County. Glacial advances from the area volcanoes and highlands have eroded the underlying bedrock, creating steep mountainsides and depositing glacial sediments such as lake deposits, till, and outwash. The rivers cut through the outwash and carried coarse and fine sediments.

Figure 1 Vicinity Map

2. GEOLOGICALLY HAZARDOUS AREAS

This chapter describes geologically hazardous areas in Lewis County, and summarizes the scientific literature concerning various types of geologic hazards and how they can affect or be affected by land use and other human activities. The chapter also presents an overview of the management and protection tools for these areas. The purpose of this chapter is to establish a basis for recommending updates to the geologically hazardous areas provisions of Article III of the WCC Chapter 16.16.300.

Lewis County is a geologically active area and some areas within the County are considered to be geologically hazardous. According to WAC 365-190-080 (4)(a), *geologically hazardous areas include areas susceptible to erosion, landslides, earthquakes, volcanic eruptions, or other geological events. These areas pose a threat to the health and safety of citizens when incompatible commercial, residential, or industrial development is sited in areas of significant hazard. Some geological hazards can be reduced or mitigated by engineering, design, or modified construction or mining practices so that risks to health and safety are acceptable.*

The following explanation of geologically hazardous areas is excerpted from the WAC (Chapter 365-190-080 [4]):

(a) Areas that are susceptible to one or more of the following types of hazards shall be classified as a geologically hazardous area:

(i) Erosion hazard;

(ii) Landslide hazard;

(iii) Seismic hazard; or

(iv) Areas subject to other geological events such as coal mine hazards and volcanic hazards including: Mass wasting, debris flows, rockfalls, and differential settlement.

(b) Counties and cities should classify geologically hazardous area as either:

(i) Known or suspected risk;

(ii) No risk;

(iii) Risk unknown - data are not available to determine the presence or absence of a geological hazard.

(c) Erosion hazard areas are at least those areas identified by the United States Department of Agriculture Soil Conservation Service as having a "severe" rill and inter-rill erosion hazard.

(d) Landslide hazard areas shall include areas potentially subject to landslides based on a combination of geologic, topographic, and hydrologic factors. They include any areas susceptible because of any combination of bedrock, soil, slope (gradient), slope aspect, structure, hydrology, or other factors. Example of these may include, but are not limited to the following:

(i) Areas of historic failures, such as:

(A) Those areas delineated by the United States Department of Agriculture Soil Conservation Service as having a "severe" limitation for building site development;

(B) Those areas mapped as class u (unstable), uos (unstable old slides), and urs (unstable recent slides) in the department of ecology coastal zone atlas; or

(C) Areas designated as quaternary slumps, earthflows, mudflows, lahars, or landslides on maps published as the United States Geological Survey or department of natural resources division of geology and earth resources.

(ii) Areas with all three of the following characteristics:

(A) Slopes steeper than fifteen percent; and (B) Hillsides intersecting geologic contacts with a relatively permeable sediment overlying a relatively impermeable sediment or bedrock; and (C) Springs or ground water seepage;

(iii) Areas that have shown movement during the holocene epoch (from ten thousand years ago to the present) or which are underlain or covered by mass wastage debris of that epoch;

(iv) Slopes that are parallel or subparallel to planes of weakness (such as bedding planes, joint systems, and fault planes) in subsurface materials;

(v) Slopes having gradients steeper than eighty percent subject to rockfall during seismic shaking;

(vi) Areas potentially unstable as a result of rapid stream incision, stream bank erosion, and undercutting by wave action;

(vii) Areas that show evidence of, or are at risk from snow avalanches;

(viii) Areas located in a canyon or on an active alluvial fan, presently or potentially subject to inundation by debris flows or catastrophic flooding;

(ix) Any area with a slope of forty percent or steeper and with a vertical relief of ten or more feet except areas composed of consolidated rock. A slope is delineated by establishing its toe and top and measured by averaging the inclination over at least ten feet of vertical relief.

(e) Seismic hazard areas shall include areas subject to severe risk of damage as a result of earthquake induced ground shaking, slope failure, settlement, soil liquefaction, or surface faulting. One indicator of potential for future earthquake damage is a record of earthquake damage in the past. Ground shaking is the primary cause of earthquake damage in Washington. The strength of ground shaking is primarily affected by:

(i) The magnitude of an earthquake;

(ii) The distance from the source of an earthquake;

(iii) The type of thickness of geologic materials at the surface; and

(iv) The type of subsurface geologic structure.

Settlement and soil liquefaction conditions occur in areas underlain by cohesionless soils of low density, typically in association with a shallow ground water table.

(f) Other geological events:

(i) Volcanic hazard areas shall include areas subject to pyroclastic flows, lava flows, debris avalanche, inundation by debris flows, mudflows, or related flooding resulting from volcanic activity.

(ii) Mine hazard areas are those areas underlain by, adjacent to, or affected by mine workings such as audits, gangways, tunnels, drifts, or air shafts. Factors which should be considered include: Proximity to development, depth from ground surface to the mine working, and geologic material.

Delineation and classification of these areas by estimated risk ensures that residential, commercial, municipal, and industrial developments are sited and constructed to avoid or reduce risk to the health and safety of citizens and to avoid or reduce risk to public resources.

2.1 OVERVIEW OF GEOLOGICALLY HAZARDOUS AREAS

Geologic hazard analysis requires a broad range of studies and site evaluations. Primary studies evaluate the surface and subsurface geology, watershed conditions, hydrology, stream flow records, topography, and landform features. Geologic mapping has been carried out in the Lewis County area and Pacific Northwest region by a number of scientists and compiled for geologic maps by the Division of Geology and Earth Resources (Schasse 2000, 1987a, 1987b; Walsh 1987; Korosec et al. 1987; Wegmann 2000; Phillips 1987; and Logan 1987).

Studies in Lewis County also include surface geology related to soils, landslides, hydrology, and channel studies from various Washington DNR watershed analysis, the USGS, Universities and project specific studies done by highway departments, towns, and private companies (Weaver 1916; Dethier 1988; Dethier and Bethel 1984; Dragovich and Brunengo 1985; Pringle 2000; Erdmann and Bateman 1956; Coombs 1989; Lasmanis and Hall 1985; Tacoma Power 1999; Lettenmaier and Burges 1981; Walsh et al. 1987; Swanson 1989; Swanson et al. 1997; Crandell and Miller 1974; Schuster 1973; Lawyer 1980; Jennings et al. 1981, Fritz et al. 1982; Weigle and Foxworthy 1962; Walsh et al. 1987; and many others).

A few of the many studies related to coal resources in and near to Lewis County include Snavely et al. 1958; Culver 1919; Roberts 1958 and annual notes on Washington State coal production in the Washington State Division of Mines and Geology quarterly news and information magazine, Washington Geology (DNR 2006).

Mapping the geologic units, soils, slopes, faults, and other features is an important first step to identifying geologic hazards. Analysis and estimates of the rate and frequency of geologic processes are also important because change in the landscape is an inherent part of geologic processes and hazards. Geologic processes form, modify, and erode the land surface over time. Some of the main forces that drive geologic processes include gravity, the hydrologic cycle, and plate tectonics. They provide the energy source that constantly and sometimes rapidly changes the earth's surface.

2.1.1 Types of Geological Hazards

Geologic hazards in Lewis County include channel migration and alluvial fan hazards, erosion, landslides, earthquakes, seismic-induced waves on lakes or reservoirs from ground motion and shoreline slumps, abandoned underground mines, and hazards associated with volcanic eruptions (e.g., ash fall, mud flows, lateral blast, and lahars).

Geologic hazards are present when there is the possibility of a geologic process affecting public health and safety or structures. Landslides can directly affect public safety because typically they can happen faster than people can react or get out of the way. Alluvial fans pose a risk to people and structures in and around the depositional areas at the mouths of creeks and rivers. During floods or debris flows, stream channels can quickly fill and shift to other portions of the alluvial fan. Earthquakes are a hazard because they cause landslides, seismic-induced waves, ground breaking, and/or liquefaction of surface soils. The dramatic beauty and abundant recreational opportunities provided by Mount Rainier, Mount Adams, and Mount St. Helens come with the threat of occasional volcanic eruptions and dangerous volcano and glacier related floods and debris flows that can be much larger than floods generated by storm runoff.

2.1.2 Landslide Hazards

Landslide hazard areas are those portions of the landscape that have existing landslides or are at risk of future landslides. Mass movement also called mass wasting is the more general classification that includes landslides. Mass wasting includes the downward and outward movement of slope-forming materials including rock, soils, artificial fills, and combinations of these materials (Gray and Sotir 1996). Mass wasting is a problem in Lewis County. A type of mass wasting is surface erosion, consisting of detachment and transport of individual particles. Surface erosion is discussed further in the erosion section. Landslides are also associated with earthquakes and volcanoes, and are discussed further in the volcanic hazards sections.

Several mass wasting classification systems are available for detailed studies, but these can be simplified into shallow slides that occur fairly rapidly, and those that are deeper and typically occur over extended time periods but can occur rapidly during earthquakes (Washington Forest Practices Board 1997). The main landslide types occurring in Lewis County include shallow rapid translational slides (also called translational slides), rockfalls and debris flows that occur rapidly, and deep-seated rotational slides (also called slumps) that typically occur more slowly. These are explained in more detail later on in this section.

Landslides involve the sliding, toppling, falling, or spreading of relatively large and often fairly intact masses along a failure surface or combination of surfaces (Gray and Sotir 1996). Landslides are generally classified based on the type of movement and slide materials (Varnes 1978). The geologic processes and mechanics of landslides are well understood but the site-specific conditions of individual slides can be quite variable (Burroughs et al. 1976; Chatwin et al. 1991; Varnes 1978; Selby 1993; Montgomery et al. 1998).

Many factors influence the occurrence and severity of landslides, including slope gradient, slope shape, surface and subsurface materials, geologic contacts or faults, heavy rainfall or rapid snowmelt, surface and subsurface water conditions, valley wall erosion by streams, slope aspect, vegetation history and condition, roads and other ground disturbance, earthquakes, and volcanic eruptions (Dragovich et al. 1993; Selby 1993; Montgomery et al. 1998). Extensive research and literature exists related to landslides, based on local, regional, and worldwide investigations (Benda and Cundy 1990; Benda and Dunne 1997; Chatwin et al. 1991; Coho and Burges 1994; Coppin and Richards 1990; Dietrich and Dunne 1978; Eisbacher and Clague 1984; Fiksdal and Brunengo 1981; Dragovich et al. 1993; Gray and Sotir 1996; Greenway 1987; Montgomery and Dietrich 1994; Montgomery et al. 1998; Selby 1993; Thorsen 1987, 1989; Tubbs 1974a, b; Varnes 1978, 1984; Wieczorek 1984; Wu et al. 1993; and numerous others).

Steep slopes are common throughout the mountains, hills, and river terrace edges of Lewis County. Steep slopes are one of the main factors leading to landslides, and are often used as a first-level screening for identifying landslide hazard areas. Contacts between relatively permeable loose surface slope materials and the denser less permeable lower layers of dense and less permeable glacial or bedrock subsurface materials, often lead to saturated contacts were slides can form (Tubbs 1974a). Some of the denser surface materials are stable when undisturbed, but can become unstable when excavated.

Loose recessional outwash and slope colluvium typically overlie rock or dense glacial clays or fine-grained advance outwash. Water builds up during wet periods, and shallow translational slides or small slumps form in the surface material. Water soaking into the ground from rainfall or snowmelt; shallow groundwater from upslope; deep groundwater from cracks in the rock or compact glacial materials; or water intercepted, diverted and concentrated by roads or other ground disturbing development reduce the internal soil strength beyond the internal soil and root strength holding the slope together, leading to slope failures

Vegetation cover plays an important part in controlling landslide formation. Vegetation reduces shallow groundwater by interception and evaporation. In addition, the complex web of roots reinforces the soil. Many surface soils on slopes over 22 degrees do not have enough strength between the individual soil grains and the additional strength provided by deep roots that help hold the slope together. Consequently, ground or vegetation disturbance on slopes can easily cause landslides depending on the slope, surface materials, water, and vegetation conditions. Steep slopes are potential indicators of slide hazards. Areas with greater than 30 percent slopes are indicated in Figures 2A and 2B. Other indicators of landslide hazards are shown in Figures 3A and 3B.

Figure 2A – Geologically Hazardous Areas - Steep Slopes

Figure 2B – Geologically Hazardous Areas - Steep Slopes

Figure 3A – Geologically Hazardous Areas – Landslide Hazard Areas

Figure 3B – Geologically Hazardous Areas – Landslide Hazard Areas

Landslides and slope stability are analyzed using landscape parameters like slope and slope shape and by modeling using the infinite slope, circular arc, or other similar approaches (Selby 1993; Montgomery et. el 1998; Gray and Sotir 1996; and others). Reduction of landslide hazards has been an ongoing effort in the region, with numerous regional and local studies appearing since the 1970s (Artim 1973a,b; Booth 1989; Miller 1973; Thorsen 1989; Tubbs 1974a,b and many others).

Landslide hazard areas can be estimated using the criteria outlined in the WAC (see the Introduction to this chapter). Landslide hazard areas have been estimated in portions of Lewis County by the Washington State DNR and USGS (Fiksdal 1978; Schasse 1987a, 1987b; Phillips 1987; Logan 1987; Korosec 1987; Walsh 1987; and Dethier and Bethel 1981; Dragovich and Brunengo 1995). Landslide hazard areas tend to be concentrated in the foothills and mountains as well as in scattered drainage ravines throughout the County.

Shallow Rapid Translational Slides

Translational slides occur along relatively shallow, fairly planar failure surfaces. Because they occur rapidly they are also called shallow rapid translational slides. This type of slide is illustrated in Figure 4. Shallow rapid translational slides are especially common in the Pacific Northwest because of steep topography, surface materials, and moisture conditions.

Translational slides are easily formed by ground disturbance, concentrated runoff, logging, and roads. Some of the causes of slides and erosion include:

- Alteration of slopes by development or roads that intercepts surface and shallow groundwater,
- Removal of vegetation that increases surface runoff and shallow groundwater, and
- Diversion and concentration of increased water runoff down steep slopes that reduces stability of the surface soils

(Montgomery et al. 2000; Bunn and Montgomery 2004; Church 2002; Gomi et al. 2002; Dunne and Leopold 1978; and others).

Figure 4. Translational Landslide

Figure 5. Rotational Landslide

The number, size, and frequency of shallow translational slides are increased by slope development such as road building, logging, clearing and grading, or other ground disturbing activities. Run-out of translational slides often extends far downslope until a low-gradient bench or valley bottom is encountered. Depending on site and moisture conditions, translational slides can form into debris flows. Consequently, the risks associated with the slide source areas and run-out paths can be hazardous and need to be evaluated in planning studies.

Deep-Seated Rotational Slides

Another common type of landslide is rotational slides or slumps. These slides typically have a deep-seated often bowl-shaped or broad curving failure surface with a steep headwall scarp and additional scarps in the slide mass. This type of slide is illustrated in Figure 5. Rotational slumps can be small, covering only a few yards (as is common along overly steep road cut and fill slopes), or they can be very large, covering many square miles. Source areas are associated with over-steepened valley walls with thick glacial and weathered bedrock deposits, geologic contacts and faults, and areas with concentrated groundwater conditions. They often occur over many months or years. Thus, human actions that alter surface conditions have relatively minor effects compared to the forces involved with the slide formation or activity.

Larger deep-seated rotational slides are characterized by a constantly shifting surface layer. Such shifting poses hazards to buildings, roads, and other facilities. Headwalls side scarps of these slides are also vulnerable to additional failures and expansion of the slide area. Remedial actions to slow the slide can be costly, and often the slide is so big that little can be done to mitigate its motion. Even small slumps can be difficult and costly to deal with. In some cases, deep-seated rotational slides can be initiated or reactivated by earthquakes or changes to water conditions related to logging road construction or other activity. Large deep-seated slides can block creeks and rivers, changing channel directions and sediment supply and transport. Smaller slumps in steeply cut slopes above buildings can be a hazard to people if buildings are damaged, generally, however, motion is slow and damage to facilities is the primary hazard.

Soil Creep and Raveling

Other types of mass movement that are common in Lewis County are soil creep and raveling. This mechanism is illustrated in Figure 6. These are ongoing gradual movements of slope materials; over many years, soil creep and raveling result in the accumulation of thicker soils at the lower portions of slopes and concave hollows. Motion is too slow to present a safety hazard but development that requires cutting into steep slopes need to plan for maintenance related to raveling and soil creep.

Figure 6. Creep

Debris Flows

Debris flows are common in upland creeks, swales, and steep slopes in Lewis County. They can be triggered by valley wall translational slides, slumps, road fill failures, diversions of surface water, logging, and other ground disturbance on the valley walls or channels within steep hill or mountain areas. This type of earth movement is illustrated in Figure 7. Debris flows occur rapidly and travel down the creek to low gradient reaches or the valley bottom where the debris comes to rest in debris deposits or alluvial fans. Active flows accumulate additional material by scouring the hillslope colluvium or valley bottom alluvium down to bedrock or dense deposits, and by carrying along the trees in the debris path. Debris flows can be small, originating from a small drainage and moving a short distance down slopes, but often debris flows are 100 to 200 feet wide and travel one-half to several miles down slopes or creek drainages. Very large debris flows may be caused by a glacial outburst flood or collapse of a volcanic cone, as occurred at Mount St. Helens in 1980. Debris flows can stall partway down a channel or at channel junctions, forming a temporary dam that breaks and results in an even larger dambreak flood and debris flow downstream. Slides along confined valleys can block the channel, forming a dam that can also start a debris flow.

Figure 7. Debris Flow

Hillslope development can contribute to debris flows by intercepting surface or shallow groundwater and diverting it down swales or into the heads of small mountain creeks. The addition of water to these areas reduces soil strength by increasing saturation. In addition, hillslope development is often associated with removal of trees, which further reduces the soil strength through loss of root reinforcement.

Debris flows move rapidly, leaving little time to move out of their way; facilities in the valley bottom of steep confined creeks and their associated alluvial fans are at risk. Huge debris flows and lahars are types of mass wasting associated with volcanoes, and will be discussed further in the Volcanic Hazards section.

Rockfall

With rockfalls, the slide material travels mostly through the air and movement is very rapid. Movement includes freefall, tumbling, and rolling of fragments of rock or highly compact soils (Norman et al. 1996; Chatwin et al. 1991). Rockfalls typically originate from steep cliffs, road cuts, or mine faces; and form a debris wedge or fan in the accumulation zone below the source area. A typical rockfall is illustrated in Figure 8. Material strength, surface gradient, joint pattern and spacing, geologic contacts, groundwater, and faulting are some of the primary factors related to rockfall occurrence. Run-out from the source area can extend quite far on steep slopes. Typically, debris forms a wedge or debris fan at the toe of the source area and is identified by landform shape, slope position, and a mix of angular, often well-drained fragments of various sizes. Over time the accumulation zone can become overly steep and prone to secondary ravel, and translational slides can occur. Rockfalls are common in the mountain areas and along mountain highways in Lewis County.

Figure 8. Rockfall

2.1.3 Erosion Hazards

Undisturbed areas of the Pacific Northwest typically have dense vegetation, decomposed organic material, and loose surface soils. These features reduce surface water runoff and associated erosion and rilling. Water runoff and erosion can occur when vegetation or surface soil layers are removed. If left unchecked, erosion areas can grow into problem areas delivering significant amounts of sediment to lakes, streams, downslope properties, and wetlands and possibly leading to landslides. Erosion is also related to channel migration, volcanic activity, lakeshore processes, agriculture, and clearing and grading.

Vegetation, landform shape, slope gradient, slope length, soil type, rainfall intensity, drainage conditions, and other factors can be used to identify erosion-prone landtypes. Soil surveys are very useful in identifying the main erosion hazard areas. The Lewis County soil survey (Evans and Fibich 1987) identifies soil units with high erosion potential that is used as a basic screening method in the present code.

Most soil types can erode when disturbed, but not all erosion is transported to adjacent properties or surface waters. Consequently, the proximity of ground-disturbing activities to surface waters will often determine the type or level of risk associated with erosion hazard areas.

Soils that are impermeable or minimally permeable generate surface water runoff with lower intensity rainfalls and begin to erode sooner than very porous soils. Vegetation, the organic duff layer, small surface depressions, and soil density all minimize runoff and erosion. Clearing, grading, and other ground disturbing activity can all reduce these factors causing surface erosion during rainstorms.

Many of the erosion-prone soils in Lewis County are associated with steep slopes or loose silty soils. Because they often overlap, erosion and landslide hazard areas are sometimes grouped together for regulatory purposes. Lewis County has many more areas with erosion hazards compared to landslide hazards. These include erosion hazards at construction sites, which are typically addressed through erosion control plans and Best Management Practices (BMP’s) associated with grading and building plans, and erosion hazards related to land or resource management, which can generate large amounts of eroded material.

2.1.4 Alluvial Fan Hazards

Alluvial fans are landforms built by sediment deposition and channel migration. Alluvial fans are localized areas of increased sedimentation downstream of locations where laterally confined creeks or rivers expand (Collinson 2002). Confinement is usually within a narrow valley or ravine eroded into an area of high relief. Expansion is usually where the stream hits the low gradient valley floor, lake, or coastal plain. The classic fan shape (often modified by local terraces or valley wall conditions) is built because of the typically rapid migration and avulsions (jumping) of the main and secondary channels, responding to large amounts of sediment and trees that deposit in the currently active channels. The major components of an alluvial fan are illustrated in Figure 9.

Figure 9. Alluvial Fans

Alluvial fans form when sediment delivery rates from eroding uplands exceed sediment transport rates on the fan. Flow expansion results in a reduction in depth and velocity of flood waters or debris flow sediment. This causes loss of energy and deposition of sediment and large woody debris (LWD) transported from the more confined and higher-gradient reaches upstream (Collinson 2002). Alluvial fans are built of coarse sediment consisting of blocks (rocks >2ft), boulders, cobbles, and gravel; channel and debris flow deposits; gravel, sand, and fines deposited overbank; and in forested regions, LWD derived from bank and valley wall erosion and landslides during large floods and especially debris flows.

During floods, sediment and LWD are deposited on the upper fan, shifting the main flood channel to either side or the center of the fan. In narrow high-gradient valleys, landslides or debris jams can temporarily dam the valley and then break, forming a dangerous dambreak flood and debris flow that surges downstream and depositing across the alluvial fan.

Fans formed by stream transport and deposition are called alluvial fans; those formed by debris flows, rockfall, or raveling are called debris fans. Often they form by a combination of these processes and are called alluvial/debris fans or more generally just alluvial fans, which is the term that will be used in this review. Most of the fans in Lewis County are built at the mouth of mountain streams, and are formed by both river and debris flow events.

Alluvial fans vary in size from small features a few yards in radius to large features several miles or more across. Alluvial and debris fan areas present a hazard to people and facilities because channel changes and sediment deposition can occur rapidly during moderate to large floods or debris flows. Floods and debris flows from mountain watersheds have high velocities and can transport large amounts of woody debris that can be very damaging as it moves across and deposits on the fan. Steep mountain valley walls, high-gradient mountain streams, forest roads, and logging can generate debris flows that scour the channel and send floods full of sediment and trees to the fans, destroying everything in their path.

The alluvial fans in Lewis County have been building for thousands of years. Upland watershed conditions influence the frequency and magnitude of deposition and channel changes on alluvial fans. Watershed disturbances like landslides, clearing, and roads that influence runoff and sediment yield accelerate the frequency and magnitude of changes on the downstream alluvial fans; but even fans formed by undisturbed watersheds continually change through channel shifting and sediment deposition. The frequency of floods from a watershed also controls the growth of alluvial deposits on fans. Flood frequency is controlled primarily by the frequency, magnitude, and duration of precipitation, as well as the runoff characteristics of the watershed. Debris flows are motivated by these same precipitation conditions and by the conditions of the valley walls and stream channels.

The limited detailed alluvial fan studies in the Pacific Northwest indicate debris flows and floods leading to net deposition and sudden creek migration have an average return interval of about 60 to 70 years (Orme 1989, 1990). Sediment cores from Lake Whatcom provide an example record that shows 7 very large and 43 large alluvial fan flood/debris flow events over the past 3,370 years, an average recurrence interval of 67 years; the 1917 and 1983 events caused considerable damage to roads, utilities, structures, and loss of life (Orme 1990). Kerr, Wood, and Leidal (2003, 2004) evaluated alluvial fan research data collected by Orme (1989, 1990), deLaChapelle (2000), and their detailed studies of Jones Creek and Canyon Creek, and found small debris flows (10,000 to 50,000 cubic yards) have an average return interval of 20 to 100 years or a 5 percent to 1 percent chance of a small debris flow occurring in any given year. Kerr, Wood, and Leidal (2003, 2004) found larger events (over 100,000 cubic yards of deposition) to have an average return period of about 400 to 600 years, or 0.25 to 0.16 percent chance of occurring in any year.

Development has been common on alluvial fans because they are outside the main river floodplains, are relatively flat compared to the steep valley walls, are well drained, have easily accessible water supplies, and generally have great views of the surrounding landscape. These qualities make alluvial fans attractive development sites along the valley edges of Lewis County.

The hazards of building on alluvial fans may not always be apparent in humid regions because dense forest cover gives the false impression that the alluvial fans are inactive (Orme 1989). In addition, incision of the main channels, formation of apparent terraces, short-term channel stability, sediment routing, and the complex response of stream channels can be difficult to interpret even with extensive detailed investigations and analysis (Cazanacli et al. 2002; Whipple et al. 1998; Muto and Steel 2004). Past problems on alluvial and debris fans include sediment deposition, channel migration, the need for repeated channel dredging or diking, damage to bridges and structures, and loss of life. These all indicate that regulation of development on fans is needed to protect public safety and reduce hazards to public and private resources. It is clear, based on local, regional, and worldwide studies of alluvial fans, as well as local past experience, that many large or small alluvial fans can be very dangerous during storms depending on watershed, valley, and channel conditions. It takes detailed geologic and watershed studies to evaluate alluvial fan hazards.

One common issue with development on alluvial fans occurs where culverts or bridges are built on the current main channel. This conflicts directly with the fundamental processes of the alluvial fan stream channel that needs to move around on the fan as sediment is delivered from upstream. The channel around the stream crossing naturally fills with sediment from a series of typical annual flows or one larger flood. This motivates the need for dredging that almost always conflicts with the fish habitat conditions of the stream.

Developments in the channel migration zone of alluvial fans are at risk of destruction and considerable planned or emergency shore armoring, dredging, diking, and other measures are required to control channel migration on developed alluvial fans. Critical structures like bridges can be built to survive most floods, but it is often economically and technically impractical to build houses and other facilities to those standards. Actions should be taken to reduce damage or losses in or near the channel migration zone of alluvial fans, including avoidance, limitations of the types of development, placing the road on piles above the fan, and buffers on the channel migration zone, and not just the present channel location.

Alluvial fans and adjacent areas are presently not explicitly regulated in Lewis County. The purpose of alluvial fan regulations is to minimize or avoid the loss of life and damage, without the need for construction of flood control devices or dredging and to allow for natural hydrologic changes along rivers and streams. Analysis of watershed, valley bottom, channel, and alluvial fan conditions is used to assess alluvial fan conditions. Some alluvial fans in Lewis County have been mapped in a variety of studies, but no single study has comprehensively mapped and classified all of them. Identifying alluvial fans is the first step in evaluating their potential hazards. Numerous alluvial fans are apparent on area topographic maps, and larger ones are identified on area geology and soils maps.

2.1.5 Channel Migration Hazards

Rivers and creeks naturally migrate and jump across valley bottoms depositing, storing, and eroding banks and valley bottom sediment (Abbe and Montgomery 2003; Collins and Sheikh 2004; Deardorff 1992; Geoengineers 2003). Channel migration builds the floodplain, terraces, and landforms along the valley bottoms. In Lewis County, the areas with the greatest potential for channel migration are the major depositional areas including deltas built into lakes and portions of most creek and river valley bottoms. Because of the numerous mountains and hills in Lewis County, alluvial and debris fans are also common landforms that are also built by channel migration during storms and debris flows.

Stream channels adjust over time to the watershed, valley bottom, and flood conditions. Creek and river channels in Lewis County have annual floods that transport and shift sediment down the channel and spill out across the floodplains. Channel banks erode and shift in response to these flood flows. Deposition and erosion along the streams and especially on alluvial fans and deltas can frequently change and the whole river or creek channel can shift or jump (channel avulsion) across the channel migration zone. Areas subject to risk due to streambank destabilization, rapid stream incision, stream bank erosion, and shifts in location of stream channels define a channel migration area.

Channel changes are natural, ongoing processes for streams and a significant part of how aquatic habitat forms and renews. Channel migration can occur gradually over a period of years or rapidly during one flood. Some reaches of a creek or river channel are confined by natural terraces, bedrock, or substantial armored levees and generally show little recent channel migration. In unconfined reaches or on alluvial fans and deltas, however, streams can experience repeated channel changes.

As part of the Comprehensive Flood Hazard Management Plan (CFHMP) Amendment for the Upper Cowlitz River Basin, the Upper Cowlitz River and Rainey Creek channel migration zone (CMZ) project was done to address channel migration conditions. The CFHMP was adopted by Lewis County in May of 2001. The CFHMP addressed several flood-related issues including reducing public exposure to risk and property damage from flooding. The plan identified direct relationships between property loss/damage from bank erosion and various types of channel migration (GeoEngineers 2003). Similar channel migration conditions occur along portions of most streams within the County. The Cispus River channel migration zone (CMZ) is indicated in Figure 10 with the CMZ of the Upper Cowlitz and Tilton Rivers is indicated in Figure 11.

Figure 10. Geologically Hazardous Areas – Cispus River Channel Migration Zone

Figure 11. Geologically Hazardous Areas – Upper Chehalis and Tilton River River Channel Migration Zone

Potential for channel migration along portions of the Nisqually, Cowlitz, and Cispus Rivers is increased due to the large runoff and sediment transport capacity of these rivers; the large sediment supply from mountain slopes, volcanic, and glacial processes; and the stored sediment along the valley bottoms. These rivers have eroded valleys into thick deposits of erodible glacial sediments interspersed with areas of harder bedrock (Weigle and Foxworthy 1962). The headwaters of the Cowlitz, Cispus, and Nisqually Rivers are glaciers on Mount Rainier and Mount Adams. As is typical of glacial streams, these rivers transport large amounts of bedload and suspended sediment from the glaciers. They also transport glacial and alluvial deposits stored along the valley bottoms and the banks and beds of the channels (Tacoma Power 1999; Bethel and Patterson 1982; Bradley et al. 1982; Dethier 1988 and Dethier and Bethel 1981).

The rivers meander or braid across portions of the valley bottoms depending on the local conditions. In the bedrock areas the river forms a narrow channel, forming canyons like downstream of Mossyrock and Mayfield Dams. The river here is trapped in the bedrock with little room for channel migration.

Prior to the dams on the Cowlitz River the relatively large sediment supply from upstream of the dams washed downstream. With the dams all bedload sediment and most of the suspended sediment is deposited in the lakes. The channel downstream of the dams is adjusting to the reduced sediment load (Tacoma Power 1999). The dropping gradient downstream and the natural stream processes still include bank erosion and channel migration downstream of the reservoirs with somewhat less motivation from the reduced sediment supply.

Channel migration areas are identified through mapping of landforms and vegetation associated with channel migration, analysis of historic maps and photographs, and surface and subsurface geologic studies. Identification of these hazards helps with land use planning, minimizes exposure to risks, reduces the need for and maintenance of protection works, and reduces damage to channel conditions essential for aquatic habitat (Brice 1977; Collins and Sheikh 2003; Dunne and Dietrich 1978; Kerr Wood and Leidal 2003, 2004; Nanson and Hickin 1996; Perkins 1996, 1993; Rapp and Abbe 2003; Shannon & Wilson 1991).

Classification of channel migration hazards can depend on many factors (Rapp and Abbe 2003). The size of a river or creek, watershed conditions, valley bottom materials and conditions, river gradient, degree and type of encroachment, and many other factors cumulatively create the potential for some rivers or creeks to migrate or jump across the valley bottom. Most river and creek channels migrate to some degree. Small creeks can be subject to substantial floods and migration similar to large rivers.

Riverine flood damage is often the result of high water impacts, combined with erosion and deposition from channel migration or shifting. Facilities near the main river or creek channel are typically at greatest risk unless there is bedrock or substantial bank protection. Historic encroachment near or in a channel migration zone motivates bank armoring, dikes, channel dredging, and other measures aimed at forcing the river into a static condition in a narrow area. This approaches are in direct conflict with the tremendous power of streams, is often costly, difficult to maintain, has up- and downstream impacts, and adversely affects aquatic habitat.

Channel migration zones often include a portion of the flood-prone area of a river or stream, but in many areas the channel migration zone is often be a lot smaller, but sometimes is larger, than the floodway. Geologic features such as terraces or bedrock banks commonly serve as boundaries to the channel migration zone. Engineered and maintained levees are considered the channel migration boundary if they meet approved building standards, but poorly built, abandoned, and undocumented levees often are not substantial enough to limit channel migration or jumping and provide nothing more than false security.

2.1.6 Seismic Hazards

Washington is situated on the collisional boundary between two tectonic plates of the crust. The offshore Juan de Fuca plate is pushing into and under the North American plate at a rate of about 3 to 4 centimeters per year. At the same time, the northward-moving Pacific plate is pushing the Juan de Fuca plate north, causing strain to accumulate (Riddihough 1984; Heaton and Hartzell 1986). Small to extremely large earthquakes are caused by the slipping and abrupt release of the accumulated strain related to the juncture of these three plates. The motions of these three plates can also build up strains on the crust underlying Lewis County causing shallow breaking (faulting) and local earthquakes.

These regional seismic conditions combined with local site conditions create earthquake hazards. Areas are at risk of damage from local shallow earthquakes and large regional earthquakes. Even areas with stable site conditions are at risk of shaking damage from large earthquakes. Areas such as lake shorelines, steep slopes, fill or loose saturated sediments, and areas closest to the main active local faults have a high probability of damage due to ground shaking, liquefaction, ground breakage, differential settling, or landslides (Noson et al. 1988; Heaton and Hartzell 1986; McCulloch 1966; McCulloch and Bonilla 1970; Foster and Karlstrom 1966; Hansen 1966; Plafker 1969; Wilson and Torum 1972; Schuster et al. 1992; Jacoby et al. 1992; Bucknam et al. 1992; Crozier 1992; Keefer 1983, 1984, 1994; Brown and Dragovich 2003).

Ground shaking and ground failures are the major factors leading to loss of life and property damage during earthquakes (Rogers et al. 1998). Seismic hazard areas are subject to a severe risk of damage as a result of ground shaking, differential settlement, or soil liquefaction. The main seismic hazards in Lewis County include ground shaking, ground breakage, landslides, liquefaction, and, lake or reservoir waves from seiches and shoreline slumps. The damage caused by seismic activity is dependent upon the intensity of the earthquake; its proximity to developed areas and population centers; the slope, thickness, consolidation, and moisture conditions of the surface and subsurface materials; and many other factors.

In the past, the primary areas considered to be at the greatest risk of earthquake damage were filled wetlands, areas of alluvial deposits subject to liquefaction, and areas where surface deposits of manmade fill or partially decomposed organic material averaged at least five feet in depth. Regional and world wide investigations over the past 60 years have shown that seismic risk is far more complex and extensive.

In the 1940s and 1950s, understanding of the need to include earthquake loadings into building designs slowly began to emerge in the west coast region (Kennedy 1996). More evidence of earthquake risks along the west coast motivated an approach where the region was segmented into seismic zones and additional analysis or earthquake loadings were added to the uniform building code throughout the 1960s. There was still considerable uncertainty and discussion on the zone boundaries.

Throughout the 1970s and 1980s, additional records and analysis of regional earthquakes and geologic mapping started to bring into focus the regional earthquake risks (Noson et al. 1988; Gower et al. 1985; Washington Geologic Newsletter 1987; and others). At the same time analysis of structural failures from earthquakes started to reveal a close relationship between seismic characteristics of a site and its response to seismic loading (Bourgeois and Johnson 2001; Kennedy 1996; Satake et al. 1996; SPNSN 2001; Williams and Huthinson 2000; Yamaguchi et al. 1997). This makes a simple zone approach to building design less effective if specific features at the site are also an additional controlling factor.

In the 1980s and 1990s, geologic understanding, based on well documented plate tectonic theories, identified the sources and mechanics of west coast earthquakes (Gower et al. 1985; Hyndman 1995; Atwater 1986, 1997; Atwater and Hemthill-Halley 1997; Schuster et al. 1992; Jacoby et al. 1992, 1997; Heaton and Hartzell 1986; Adams 1990; Applied Technology Council 1994; Rogers et al. 1998 at http://pubs.usgs.gov/prof/p1560/; and numerous others).

Proximity to the fault that causes an earthquake is a major factor in determining how much seismic energy impacts the local area. Small earthquakes on faults in Lewis County can cause ground shaking similar to larger earthquakes centered farther away. Moderate quakes on local faults, or larger ones deeper or farther west, can both be very damaging in Lewis County. The mountains and valleys are moved and uplifted by region-wide pressures created by the motion of the ocean crust into and under the continental crust (Atwater 1987, 1988). The result of this movement is that the entire County is tectonically active.

The main rock formations and valleys of Lewis County form depositional basins containing unconsolidated saturated deposits that can amplify the ground-shaking energy and disturbance during an earthquake. Shallow, loose and saturated soils can easily deform or liquefy during ground shaking and are found in many areas throughout the County, such as the Cowlitz or Chehalis valley bottoms and valley walls. Many of these areas can be identified based on the county soils survey completed in 1980 (Evans and Fibich 1987)

Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. During shaking or rapid loading water between the soil grains exerts a pressure on the soil particles that influences how tightly the particles are pressed together. During an earthquake, shaking can cause the water pressure to increase to the point where particles can readily move as a liquid or plastic flow causing settling.

The results of liquefaction include loss of bearing strength resulting in slumping and sinking of a structural foundation. Differential settlement of foundations can cause shear forces in the structure that cause cracks or failures. Increased pressure on structures such as foundations or retaining walls can cause them to deflect or fail. On structures such as bridges, lateral pressure can cause supports to deflect which can push the foundation out of place to the point where bridge spans loose support or are compressed to the point of breaking. Lateral spreading can range from slight to extreme movement of soils on a gradient and can result in cracks and fissures or substantial block sliding. Potential liquefaction hazard areas in Lewis County based on soil types are depicted in Figures 12A and 12B.

Figure 12A. Geologically Hazardous Areas – West – Liquefaction Zones

Figure 12B. Geologically Hazardous Areas – East – Liquefaction Zones

Unconsolidated deposits around lakes, especially delta deposits, are made of loose, saturated materials that often have steep fronts. Shaking from small local or large regional earthquakes can cause slumps in these deposits, which can be dangerous to shore facilities. Displacement from such slumps generates waves that wash onto shore and, causing inundation and impact hazards (Foster and Karlstrom 1966; Hansen 1966; McCulloch 1966; McCulloch and Bonilla 1970; Plafker 1969; Wilson and Torum 1972). This can happen so rapidly that evacuation would not be effective.

2.1.7 Volcanic Hazards

Lewis County includes valleys draining the south side of Mount Rainier, the Cowlitz and Nisqually River valleys, and the Cispus River valley from the northwest side of Mount Adams. The USGS Cascade Volcano Observatory has an extensive amount of published and web accessible information that is used in this section to summarize volcanic hazards in Lewis County from Mount Rainier, Mount Adams, and Mount St. Helens (CVO 2006).

Future activity is likely to create a variety of hazards for the region. Most of the volcano related geologic hazards would only affect the immediate vicinity of the volcanoes. However, tephra falls, debris flows, and lahars could affect great numbers of people far from the volcanoes (Hobblitt et al. 1998; Crandell 1973; Crandell and Mullineaux 1967). Mount Rainier and Mount Adams are the most likely sources of volcanic hazards in Lewis County, but other nearby volcanoes such as Mt. St. Helens or Mount Hood, could deposit ash in the area. Volcanoes like Mount Rainier are capable of violent eruptions that deposit enormous amounts of material over the landscape (Hoblitt et al. 1998, Scott et al. 1995, King County 2004). Tephra is commonly dispersed by winds over broad areas, and although its effects can be quite disruptive, it is usually not lethal. In contrast, lahars are restricted to valleys that originate at the volcano, but their effects can be very severe. In terms of their potential effects, lahars from Mount Rainier constitute the greatest volcano hazard in the Cascade Range. Worldwide, over 200,000 people have been killed by volcanic hazards in the past 500 years. This is far more then in previous centuries because of the increased numbers of people living near volcanoes (Tilling 1991).

Mount Rainier

Mount Rainier towers above the surrounding region with an elevation of 14,410 ft (4393 meters). Mount Rainier poses a variety of geologic hazards, both during inevitable future eruptions and during the intervening periods of repose (Hoblitt et al. 1998). Mount Rainier has erupted about 20 times beginning about 9,700 yr B.P. (before present). Multiple eruptions occurred from 6,800 to 5,000 yr B.P. About 5,000 yr B.P., eruptions culminated in the formation of the Osceola mudflow. Cone building ensued between 5,000 and 4,500 yr B.P. More recent notable eruptions include four to five between 2,600 and 2,200 yr B.P., two at about 1,000 yr B.P., one at about 500 yr B.P., and one at about A.D. 1850.

The written history of Mount Rainier encompasses the period since about A.D. 1820, during which time one or two small eruptions, several small debris avalanches, and many small lahars (debris flows originating on a volcano) have occurred. Prehistoric deposits record the types, magnitudes, and frequencies of past events, and show which areas were affected. (Hobblit et al. 1998).

At Mount Rainier, as at other Cascade volcanoes, deposits produced since the latest ice age (approximately during the past 10,000 years) are well preserved. Studies of these deposits reveal that we should anticipate potential hazards from some phenomena that only occur during eruptions and from others that may occur without eruptive activity (Hobblit et al. 1998). Tephra falls, pyroclastic flows and pyroclastic surges, ballistic projectiles, and lava flows occur only during eruptions. Debris avalanches, lahars, and floods commonly accompany eruptions, but can also occur during dormant periods.

Geologic hazards related to Mount Rainier include lahars (mud or debris flows), ash (tephra) fall, landslides or debris avalanches, pyroclastic flows and surges, ash clouds, ballistic debris, lava flows, lateral blasts, and glacial outburst floods (Hoblitt et al. 1998, Pringle 2000). These and other similar hazards have occurred recently in western Washington (Mount St. Helens) and are clearly identified in the geologic record of Mount Rainier and the other similar nearby active Cascade volcanoes such as Mount Adams, Mount Hood, Glacier Peak, and Mount Baker. Glacial ice has influenced eruptions and amplified erosion throughout the lifetime of these volcanoes (Driedger 1993; Driedger and Kennard 1986). Existing information suggests tephra falls, lahars, and debris flows may be the greatest volcanic hazard in Lewis County because of the distance they can travel down valleys and their frequent history at the nearby volcanoes (Hoblitt et al. 1998; Scott et al. 1995; Crandel 1973; Crandell and Mullineaux 1967). Lahars and ash fall are triggered by volcanic eruptions, but some types of debris flows and outburst floods can occur without apparent volcanic activity.

During the past 10,000 years, at least 60 lahars of various sizes have moved down valleys that head at Mount Rainier. All these can be grouped into two categories, called cohesive and non-cohesive lahars. Cohesive lahars form when debris avalanches originate from water-rich, hydrothermally altered parts of the volcano. They are cohesive because they contain relatively large amounts of clay derived from chemically altered rocks. Non-cohesive lahars, in contrast, contain relatively little clay. Mount Rainier’s non-cohesive lahars are triggered whenever water mixes with loose rock debris, such as the mixing of pyroclastic flows or pyroclastic surges with snow or ice; relatively small debris avalanches; unusually heavy rain; or abrupt release of water stored within glaciers.

The largest lahar originating at Mount Rainier in the last 10,000 years is known as the Osceola Mudflow. This cohesive lahar, which occurred about 5600 years ago, was at least 10 times larger than any other known lahar from Mount Rainier. It was the product of a large debris avalanche composed mostly of hydrothermally-altered material, and may have been triggered as magma forced its way into the volcano. Osceola deposits cover an area of about 212 square miles (550 square kilometers) in the Puget Sound lowland, extending as far as the Seattle suburb of Kent, and to Commencement Bay, now the site of the Port of Tacoma.

At least six smaller debris avalanches have spawned lahars in the past 5,600 years. One of these, the Electron Mudflow, which was caused by a slope failure on the west flank of Mount Rainier about 600 years ago, has not been correlated with an eruption. The Electron Mudflow was more than 30 meters (yards) deep where it entered the Puget Sound lowland at the community of Electron. Its deposits at Orting are as much as 6 meters (yards) thick and contain remnants of an old-growth forest.

Large non-cohesive lahars at Mount Rainier are associated with volcanism. About 1,200 years ago, a lahar of this type filled valleys of both forks of the White River to depths of 60 to 90 feet (20 to 30 meters) and flowed 60 miles (100 km) to what is now the City of Auburn.

Hot rock fragments flowing over glacier ice and snow generated huge quantities of melt water, which mixed with the rock debris to form lahars. Less than 2200 years ago, another lahar of similar origin, named the National Lahar, inundated the Nisqually River valley to depths of 30-120 feet (10 to 40 meters) and flowed all the way to Puget Sound. More than a dozen lahars of this type have occurred at Mount Rainier during periods of volcanism in the past 6,000 years.

Circumstances conducive to future debris avalanches and lahars, including substantial volumes of hydrothermally altered rock, substantial topographic relief, great volumes of ice, and the potential for renewed volcanism are all present at Mount Rainier. Lahars are a greater threat to community’s downvalley from Mount Rainier than any other volcanic phenomenon (Hoblitt et al. 1998).

Mount Adams

Mount Adams is a 12,276 feet (3,742 meter) stratovolcano that dominates the 500 square miles (1,295 square kilometers). The Mount Adams Volcanic Field is partly in southeast Lewis County. Mount Adams has been less active during the past few thousand years compared to nearby Mounts St. Helens, Rainier, and Hood (Hildreth and Fiersthin 1994). Future eruptions will probably occur more frequently from vents on the summit and upper flanks of Mount Adams than from vents scattered in the volcanic fields beyond (Scott et al. 1995). Large landslides and lahars not related to eruptions are most likely the most destructive, far-reaching hazards of Mount Adams (Scott et al. 1995).

Mount Adams is second in eruptive volume only to Mount Shasta, and it far surpasses its loftier neighbor Mount Rainier. Mount Adams's main cone exceeds 47 cubic miles (200 cubic kilometers). At least half as much more was eroded during late Pleistocene time to form earlier high-standing components of the compound edifice. The peripheral basalt adds approximately another 17 cubic miles (70 cubic kilometers) (Wood and Kienle, eds., 1990).

Mount Adams is composed of lava flows and fragmental rocks of basaltic andesite and andesite. Numerous satellitic vents on the flanks of the volcano erupted rocks ranging from basalt to dacite. Most of the main cone is younger than 220,000 years (Hoblitt, et al. 1987). There has been seven postglacial lava flows issued from flank vents, the youngest of which is between 6,850 and 3,500 years old.

Debris avalanches and lahars affected several valleys around the volcano during postglacial time; the longest lahar extended at least 32 miles (52 kilometers) from the volcano. A large amount of hydrothermally altered material in this and one other lahar and in one debris avalanche implies they originated as avalanches of wet, altered, clay-rich debris from near the summit. The youngest such event was a debris avalanche that descended the southwest flank in 1921 (Hoblitt, et al. 1987).

Numerous debris flows generated by glacial and weather conditions occur frequently at Mount Adams, but typically affect areas within only a few miles of the volcano. Postglacial eruptions and weak, diffuse fumarolic emissions in the summit area suggest that the volcano is capable of erupting again (Hoblitt, et al. 1987). Nearly all the high cone above 7,500 feet (2,300 meters) in elevation was constructed during latest Pleistocene time, probably between 20 and 10 thousand years ago (Wood and Kienle 1990).

There have been no recorded eruptions of Mount Adams, and of the 11 Holocene vents, none is known certainly to have erupted products younger than 3,500 years. Seven of the Holocene eruptions took place at flank vents 6,500 to 8,200 feet (2,000 to 2,500 meters) in elevation and the other four vents are peripheral to the main cone at 3,600 to 5,200 feet (1,100 to 1,600 meters).

During the past one million years, numerous volcanic vents were active throughout south-central Washington, from Vancouver to Goldendale. Most were probably active for relatively short times ranging from days to tens of years. Unlike Mount Adams, which has erupted repeatedly for hundreds of thousands of years, these vents typically did not erupt more than once. Each erupting vent built a separate, small volcano, and over time a field of numerous overlapping volcanoes was created. Clusters of these vents define the Mount Adams, Indian Heaven, and Simcoe Mountains volcanic fields. In addition, the Goat Rocks volcanic center lies 18 miles (30 kilometers) north of Mount Adams.

About 9,000 years ago, the Big Lava Bed issued from a small volcano less than 1,000 feet (300 meters) high and partly filled the northwest part of the Little White Salmon River drainage basin with a thick lava flow almost 10 miles (16 kilometers) long. A few ancient lava flows were sufficiently large to flow down tributary valleys, spread out on the floor of the Columbia River Gorge, and dam the river to form a lake. The river then cut a new channel around or through the lava flow.

The present cone was formed before the last major glaciation, which occurred between 25,000 and 12,000 years ago (Porter 1983). The lowermost lava flows exposed in the main cone have an age of about 460,000 years B.P. and overlap the eroded remnants, which range in age from 460,000 to 520,000 years B.P., of an older andesitic center called the Hellroaring volcano (Hildreth and Lanphere, 1994).

At least five lahars and a debris avalanche, originating at Mount Adams, moved into the White Salmon River drainage basin during the past 12,000 years. The deposits produced by these lahars range in volume from 4 to 66 million cubic meters and moved as much as 60 kilometers down valley. About 6,000 years ago, the largest of the lahars inundated about 15 square kilometers of the lowland near Trout Lake and dammed a tributary stream to form Trout Lake. About 200 years ago, another lahar filled valleys to depths as much as 50 meters, and produced run-ups of as much as 30 meters on objects in its path, but left only thin veneers on valley sides and floors. Three smaller lahars and a debris avalanche of 1921 extend between 5 and 15 kilometers from Mount Adams.

During the past 10,000 years, the steep upper slopes of Mount Adams have produced several notable debris avalanches. In 1921, about 5 million cubic yards (4 million cubic meters) of altered rock fell from the head of Avalanche Glacier on the southwest flank of the volcano and traveled almost 4 miles (6 kilometers) down Salt Creek valley. The debris avalanche contained or acquired sufficient water to partly transform into small lahars (Scott et al. 1995).

Ancient debris avalanches of much larger size have also occurred at Mount Adams, and these formed lahars that traveled far down the White Salmon and other valleys. An avalanche of roughly 90 million cubic yards (70 million cubic meters) initiated the largest of these lahars about 6,000 years ago. This lahar inundated the Trout Lake lowland and continued down the valley of the White Salmon River at least as far as Husum, more than 35 miles (55 kilometers) from Mount Adams. The lahar deposit left in the lowland varies from 3 to 65 feet (1 to 20 meters) thick. It is clearly visible today as a sediment layer in the banks of the White Salmon River and as isolated blocks, some more than 16 feet (5 meters) in diameter, that protrude from fields and meadows (Scott et al. 1995).

2.1.7.2 Debris Flows or Lahars

Debris flows and mud flows are dense slurries of water-saturated debris (including rock, soils, and trees) that form when loose masses of material move downslope (Gardner et al. 1995). They are sometimes called lahars when derived from a volcano Lahars often occur during eruptive periods or from thick, steeply sloped deposits years after an eruption, but also occur without any apparent association to eruptive events. Both debris and mud flows contain a high concentration of rock debris to give them the internal strength necessary to transport huge boulders, as well as buildings and bridges, and to exert extremely high impact forces against objects in their paths (Brantley and Power, 1985).

Debris flows are coarser and less cohesive than mudflows. As lahars become diluted in the downstream direction they become hyperconcentrated streamflows. Lacking internal strength, the mixture of rock debris and water takes on different flow properties. The coarser debris in this type of flow is no longer held in suspension by matrix strength and therefore settles to the bottom of the flow.

Debris flows and lahars can be of any size. They may be as small as a few inches wide and deep, flowing less than one yard per second. Steep, unvegetated slopes during a heavy rain are often good sites to observe such small flows. At the other extreme, they can be hundreds of feet wide, tens of feet deep, flow at several yards per second, and travel miles from a volcano. Such catastrophic lahars are triggered by volcanic eruptions or by massive landslides such as the one that occurred on May 18, 1980, at Mount St. Helens.

Lahars are commonly initiated by large landslides of water-saturated debris caused by heavy rainfall eroding volcanic deposits; sudden melting of snow and ice near a volcanic vent or on the flanks of a volcano by pyroclastic flows; or breakout of water from glaciers, crater lakes, or from lakes dammed by volcanic eruptions. Since 1980, lahars have formed by all of these processes at Mount St. Helens.

Stratovolcanoes, like all of the Cascade volcanoes, are composed of an accumulation of relatively weak rock and ash deposits that are altered by weathering and hot fluids. Such volcanoes are very steep because of glacial erosion, dome building, and landslides. This leaves them vulnerable to small and large debris flows that can move great distances down valleys at speeds of 6 to 90 miles per hour, with average speeds of 20 to 40 miles per hour.

Debris flows grow larger as they move down valley, scouring the valley bottom and picking up additional water, sediment, and trees. Debris flows and lahars and pyroclastic flows and surges can all profoundly alter river locations and the valley bottoms. Sediment supply and deposition along downstream rivers is greatly increased for many years to decades. The potential for channel migration is increased in downstream river reaches because of the greater sediment supply and channel storage.

Debris flows can travel great distances down valleys, and debris-flow fronts can move at high speeds—as much as 50 miles per hour. Debris flows produced during an eruption of Cotopaxi volcano in Ecuador in 1877 traveled more than 198 miles down one valley at an average speed of 17 miles per hour (Macdonald 1972). High-speed debris flows may climb valley walls on the outsides of bends, and their momentum may also carry them over obstacles. Debris flows confined in narrow valleys or by constrictions in valleys can temporarily thicken and fill valleys to heights of 300 feet or more (Crandell 1971).

Debris flows from Mount Rainier and Mount Adams pose a risk to life and property from burial or impact People and animals also can be severely burned by debris flows. Buildings and other property in the path of a debris flow can be buried, smashed, or carried away. Because of their relatively high density and viscosity, debris flows can move and carry away vehicles and other objects as large as bridges and locomotives. Debris flows follow existing drainages; the risk tends to decrease with distance downstream and with height above the river channel. They are a hazard in association with volcanic eruptions and for many years following major eruptions; as accumulated loose material is remobilized during wet periods.

Because debris flows are confined to areas downslope and downvalley from their points of origin, people can avoid them by seeking high ground. Debris flow hazard decreases gradually downvalley and with increasing altitude above the valley floors. People seeking to escape flows should climb valley sides rather than try to outrun debris flows in valley bottoms. During eruptive activity or precursors to eruptions, local government officials may ask for prompt evacuation of areas likely to be affected. Lahar and debris flow hazard zones were estimated by the USGS for Mount Rainier (Hoblitt et al. 1998) (Figure 13) and for Mount Adams (Scott et al. 1995) (Figure 14).

Figure 13. Mount Rainier Volcanic Hazard Zones (CVO 2006)

Figure 14. A Portion of the Mount Adams Volcanic Hazard Zones Map Related to Debris Avalanches and Lahars (Scott et al. 1995).

2.1.7.3 Pyroclastic Flows, Pyroclastic Surges, and Ash Clouds

Pyroclastic flows occur during explosive eruptions. Pyroclastic flows or surges are avalanches of hot (300° to 800° C), dry volcanic fragments and gasses that travel down the flanks of the volcano at speeds up to 200 miles per hour. The mass, high temperature, and great mobility of pyroclastic flows makes them very destructive and dangerous, posing a lethal hazard by incineration, asphyxiation, burial, and impact. They are difficult to escape because of their high speed, so evacuation must begin before they occur. Prediction and cautious area closures are essential to hazard management in areas susceptible to pyroclastic flows.

Pyroclastic flows tend to follow existing valleys and have enough energy to overtop ridges and hills. Pyroclastic surges are even more energetic events associated with pyroclastic flows and are less restricted by topography. Debris flows can be generated when pyroclastic flows interact with snow or ice. Because of the ice and snow on Mount Rainier and Mount Adams, pyroclastic flows from the upper slopes are likely to form debris flows; large ones would move downstream as debris flows or floods (Hoblitt et al. 1998, Scott et al. 1995). Pyroclastic and debris flow hazard zones were estimated by the USGS for Mount Rainier (Hoblitt et al. 1998) (Figure 13) and for Mount Adams (Scott et al. 1995) (Figure 14).

Deposits of pyroclastic flows and surges exist at Mount Rainier, but they are not abundant. Pyroclastic-flow deposits about 2,500 years old are found in the South Puyallup River Valley, about 7.5 miles (12 kilometers) southwest of the volcano's summit. A thin surge deposit about 1000 years old has been found approximately 7 miles (11 kilometers) northeast of the summit, in the White River Valley. The apparent lack of pyroclastic flow and surge deposits may mean that Mount Rainier produces few of them. However, a more likely reason is that most pyroclastic flows and surges are converted to debris flows as they pass over snow and ice. The hot rock fragments melt snow and ice and then mix with the melt water to form lahars. At least some of the many lahars produced by Mount Rainier in the past 10,000 years formed in this manner (Hoblitt et al. 1998).

2.1.7.4 Landslides and Debris Avalanches

Landslides and debris avalanches can occur from volcanoes. Like debris flows, such events may not necessarily be accompanied by an eruptive event. Landslides or debris avalanches from volcanoes can range from relatively small slides off of the steep, often glaciated slopes, to large slides similar to the one that led to the 1980 eruption of Mount St. Helens. The 1980 Mount St. Helens eruption started with the swelling of the mountain that made the north side overly steep and unstable, leading to a massive landslide that led to the eruption (Schuster 1989). The north and northeast sides of most of the Cascade volcanoes are very steep because this is where alpine glaciers have been more active, as was the case with Mount St. Helens. When volcanoes swell, as new magma pushes up under the mountain, the steeper sides are more vulnerable to landslides. Over dozens to hundreds of years, dense lava typically pushes up, rebuilding the top of the mountain, often with a slightly different center, eventually setting the stage for another eruption. Smaller landslides are very hazardous only on the slopes and valleys around the volcano; large ones can travel many miles down the valleys, forming into debris flows (Scott et al. 2001).

2.1.7.5 Ash Falls or Tephra Plumes

Ash or tephra is ejected rapidly into the air during eruptions. The distance this material travels and the depth to which ash and larger rock fragments may cover the ground depends on distance from the mountain and the prevailing wind directions during the eruption (Wolfe and Pierson 1995; Gardner et al. 1995). The larger particles falls near the mountain and finer ash falls further downwind. Ash fall hazards can vary from life-threatening to a nuisance. Clouds of fine tephra can block sunlight, greatly restrict visibility, and thereby slow or stop vehicle travel. Such clouds are commonly accompanied by frequent lightning. When inhaled, tephra can create or aggravate respiratory problems. Accumulation of more than about 4 inches (10 centimeters) of tephra on the roof of a building may cause it to collapse. Even thin tephra accumulations ruin crops and can be toxic to cattle. Wet tephra can cause power lines to short out. Fine tephra is abrasive and can damage mechanical devices and increase maintenance problems. Finally, tephra clouds are extremely hazardous to aircraft, because engines may stop and pilots may not be able to see.

Tephra deposit thicknesses and particle sizes usually decrease with increasing distance from the volcano. Near the vent, large eruptions can produce tephra thicknesses of many yards, containing fragments as large as 10 to 20 inches across. At hundreds of miles from the vent, tephra deposits typically consist of a trace to a few inches of dust to silt-sized particles.

Mount Rainier is a moderate tephra producer relative to other Cascade volcanoes, and Mount Adams is a meager tephra producer. The most serious tephra hazards in the region are due to the proximity of Mount St. Helens, the most prolific producer of tephra in the Cascades. The region around eastern Lewis County has the highest probability of tephra fall of anywhere in the western contiguous United States, owing to its location just downwind of Mount St. Helens.

Figure 15 shows probabilities for a tephra fall of approximately 4 inches or greater. Experience shows that roof failures tend to increase as the tephra thickness approaches 4 inches. Consequently Hobblett et al. (1998) portrayed tephra hazard with contour maps of the estimated annual probability of tephra accumulations of one centimeter (0.4 inch) or more and ten centimeters (4 inches) or more for the combined influence of all of the Cascade volcanoes.

Figure 15. Tephra or Ash Accumulation Over 10 Cm (4 Inches) or More Using Combined Estimated Probabilities for the Pacific Northwest Cascade Volcanoes (CVO 2006).

2.1.7.6 Ballistic Debris

Ballistic debris includes pebble- to boulder-size rock fragments blown from the volcano during steam explosions or eruptions. Particles thrown from the vent on ballistic arcs, like artillery shells, are called ballistic projectiles. Rocks can be blasted up to about six miles into the sky but the maximum range of ballistic projectiles rarely exceeds 3 miles from the vent, and most projectiles are less than a 3 feet across. The chief hazard from ballistic projectiles is from direct impact. Projectiles may still be quite hot when they land, and can start fires if they land near combustible materials.

During active volcanic periods, high-speed impact by falling debris can pose a significant hazard. Hazard from ballistic projectiles on Mount Rainier and Mount Adams are primarily within the National Park and U.S. Forest Service lands at the edges of Lewis County in the headwaters of the Nisqually, Cowlitz and Cispus River valleys (Hoblett et al. 1998, Scott et al. 1995).

2.1.7.7 Lava Flows

Lava flows are masses of hot, partially molten rock that flow from the volcano and move downslope until they stop, cool, and solidify. They typically follow existing valleys. Lava from Cascade volcanoes is very stiff because of its mineral composition and consequently flows very slowly. Lava flows are usually not a safety risk because they flow slowly and their paths can be estimated once they start. Lava flows can generate debris flows if in contact with ice or snow. They can damage structures by burial or burning because they generally cannot be stopped, and also can start forest fires.

Lava flows may accompany explosive eruptive activity, but they occur more often after explosive activity declines. Andesite lavas typical of Mount Rainier tend to be very viscous and rather slow moving. On gentle slopes, they may move much more slowly than a person can walk. Although people and animals can escape them, lava flows destroy everything in their paths either by fire, impact, or burial, and can give off toxic gasses.

The primary hazard to people from lava flows is low, but a more serious hazard arises when such flows come into contact with snow and ice. The result is rapid melting, which is capable of generating floods and lahars. Some lahars from Mount Rainier may be the indirect products of lava flows. Potential direct lava flow hazard is found on the top and flanks of Mount Rainier and Mount Adams and are found in the upper parts of the Nisqually, Cowlitz, and Cispus River valleys in Lewis County on National Park and U.S. Forest Service lands.

The only lava flows known to have been erupted from Mount Rainier in the past 10,000 years are those that built the summit cone, which was constructed within the past 5,600 years. Some of these flows probably extended down the east side of the volcano, where their remnants form ridges of rock along the central part of Emmons Glacier.

2.1.7.8 Lateral Blasts

Lateral blasts are an explosive eruption where much of the energy is directed horizontally away from the eruptive center instead of up. They vary by size and large ones are rare. The Mount St. Helens 1980 eruption is the classic example of a lateral blast. In that blast a 570° F mixture of rock, gas, and ash moved up to 650 miles per hour crossing over ridges as high as 2,500 feet above the valley floor and extending up to 15 miles from the source (Gardner et al. 1995). Most trees in this zone were knocked down and nearly everything perished. The Mount St. Helens lateral blast was preceded by several months of deformation of the mountain, so the hazard zone may be predictable with further research and monitoring (Gardner et al. 1995). Hazard from lateral blasts on Mount Rainier and Mount Adams are primarily within the National Park and U.S. Forest Service lands at the edge of Lewis County in the headwaters of the Nisqually, Cowlitz and Cispus River valleys (Hoblett et al. 1998, Scott et al. 1995).

2.1.7.9 Glacial Outburst Floods

Glaciers can block meltwaters forming small and sometimes large lakes. Lake outlet drainage can change, sometimes rapidly, draining the waters and forming floods, sometimes much larger than generated from rainfall-runoff processes and outburst floods can occur at any time without warning. Glaciers are common on volcanoes and hydrothermal conditions increase the potential for glacial outburst floods. Contact of ice and frozen ground with hydrothermal waters or lava flows cause rapid melting and floods.

2.1.8 Mine Hazards

Coal has been mined in Washington since 1853 (Figure 16). Although current production is from surface mines, nearly all coal produced prior to about 1970 came from underground workings. Since early in this century, Washington State law has required mine operators to submit detailed plans of all underground coal operations to the state on an annual basis. About 1,100 individual maps representing about 230 mines comprise the Washington State coal mine map collection. The maps are an invaluable source of information for mine subsidence hazard evaluation and mitigation, structural geology, coal exploration, resource evaluation, and historical research.

Mine hazards in Lewis County mostly relate to coal mines that were active in the first half of the 20th century. Mine hazard areas are underlain by abandoned mine shafts, secondary passages between shafts, tunnels, or air vents. Mine hazards include subsidence, which is the uneven downward movement of the ground surface caused by underground workings caving in; contamination to ground and surface water from tailings and underground workings; concentrations of lethal or noxious gases; and underground mine fires.

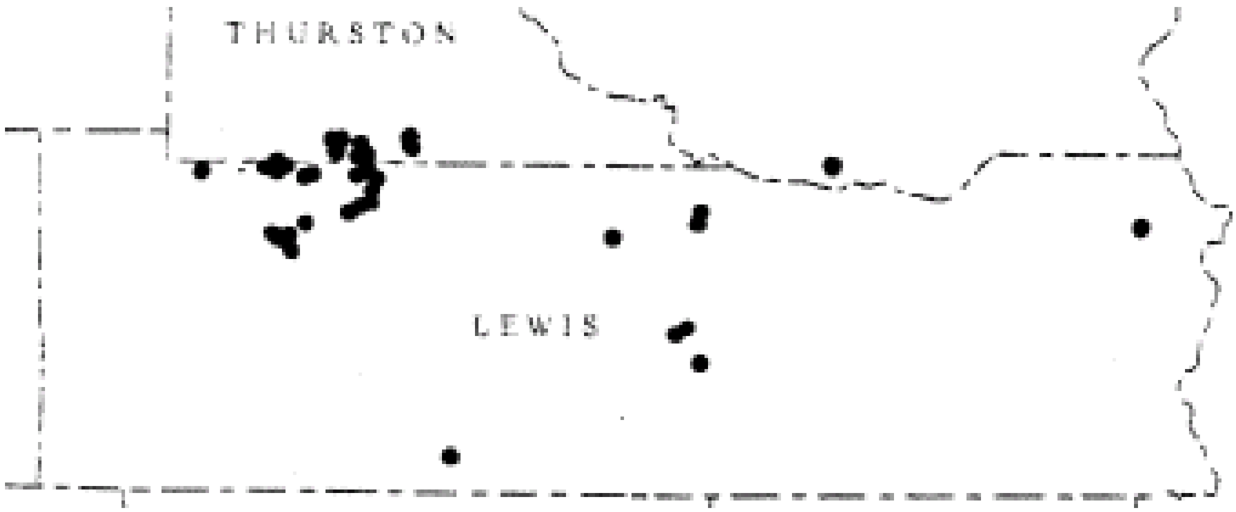

Figure 16. Coal mines in Lewis County (Schasse et al. 1994).

The Washington State Coal Mine Map Collection shows both abandoned mines and known mine areas, identifying where coal mine hazards may occur in Lewis County (Figure 17 and Figure 18)(Schasse et al. 1994; USGS 1984, 1958; WADNR 1978; Washington Division of Mines and Geology 1956). This coal mine map index lists 31 companies with coal field workings in Lewis County dating from 1906 thru 1972, with most before 1948 (Schasse et al. 1994). Metal mines are tracked in Washington's Inactive and Abandoned Metal Mine Inventory and Database (Norman 2000). Major abandoned metal mines and their watersheds are listed in Derkey et al. (1990). Only two abandoned metal mines are shown in the Lewis County Area.

Evaluation of individual sites in known mine areas can be used to guide development in these areas or to support avoidance of the area. The mine areas in Lewis County appear to be fairly well known from historic reports.

An additional category of mine workings is metal mines for copper, lead, zinc, silver, gold and other metals. As indicated in Figure 18 several abandoned mines are present in Lewis County.

Hazards associated with abandoned coal mines are directly related to mine collapse and land subsidence. The potential for coal mine collapse and land subsidence is influenced by many factors. Primary factors include the height of the mine void, depth and strength of the rock roof, and type and amount of roof support within the mine (Dunrud 1976; Crowell 1995). In general, the vertical component of subsidence does not exceed the height of the mine void. The potential for subsidence decreases with the strength and thickness of the roof rock due to bridging, which can prevent land-surface subsidence, despite collapse of the mine roof at great depth. The potential for land subsidence increases in weak or fractured rock, and where abandoned mines are open to the surface. Rock strength also controls the surface area affected by mine collapse and subsidence. The minimum area of subsidence is determined by the area of roof collapse plus an additional area determined by the internal friction angle of the rock (an inherent property related to compressive rock strength). A greater area of subsidence will occur above weak rock with a low friction angle. The deterioration of coal or rock pillars and wooden timbers used for roof support in mines can increase the likelihood of mine collapse, particularly for older mines.

Figure 17. Coal mines in Lewis County (Schasse et al. 1994).

Figure 18. Locations of Some Major Abandoned Metal Mines and Their Watersheds in Washington, Based On Data From Derkey And Others (1990).

Figure 19. Abandoned Mine Trough Subsidence

2.2 HUMAN ACTIVITY AND GEOLOGICALLY HAZARDOUS AREAS

Natural geologic processes create hazardous areas that are easily recognized as dangerous. In many situations, however, the hazards are not so obvious and experienced scientists and engineers are needed to evaluate risks. Some geologic processes are easily influenced by land management actions, while others occur at a scale or magnitude over which we have limited control. Many types of landslides and surface erosion are easily caused or increased above natural levels by human activities along the coast, near streambanks, and on hillslopes. Larger slides generated by volcanic eruptions or earthquakes are not influenced by land use management, but recognizing their potential is still important for development planning and for safe response when they occur. Geologically hazardous areas can sometimes be identified based on present site conditions and past events. Identifying the magnitude and frequency of past geologic events can help identify current geologic hazards. However, conditions can change over time and the influence of past and proposed management needs to be considered.

2.2.1 Landslides and Erosion Hazards

People affect landslide erosion hazard areas by clearing vegetation, grading and excavating, modifying drainage, and developing on steep slopes. Clearing vegetation changes the overall stability of a slope and often increases runoff, erosion, or landslide hazards downslope or downstream. Clearing and grading reduce or remove the interception of precipitation provided by vegetation, the litter and loose surface soil layer, and on-site ponding that occurs during short periods of intense rainfall (Konrad 2000, 2003; Konrad and Burgess 2001; Booth 1990; Burgess et al. 1998). Removing vegetation, especially deep-rooted mature plants, reduces or removes the strength that roots provide to the soils on river banks and steep slopes (Bennett and Simon 2004; Gray and Barker 2004; Schiechtl 1980; Schiechtl and Stern 1996). Roads, ditches, and clearing or modifying the vegetation and litter layer increase runoff and often generate runoff where only infiltration previously occurred. Increased stormflow runoff is then collected by surface and subsurface drains, ditches, and roads, and directed down swales and into creeks. The combined cumulative impact of all of these actions causes surface erosion and landslides if high risk areas are not avoided and adequate control measures are not provided and maintained.

Lakeshore erosion is affected in a similar way by excavation and grading that removes some or all of the vegetation and natural slope structure and strength. Lake shorelines, river channels, and streambanks are naturally changing on at least an annual time scale, due to floods and storm waves. These natural processes combine with development modifications, causing even more rapid erosion and slides. Building structures, yards, roads and other development near these active areas create the need to “fix“ the bank, which often can adversely impact nearby neighbors, wetlands, and aquatic habitat conditions.

Erosion and stormflow runoff damage are typically minimized by restricting or conditioning development and agricultural management practices. The County soil survey and GIS data can help to identify the general slopes and materials that are most at risk of erosion. GIS analysis can identify the general erosion and landslide hazard areas, but site-specific data and analysis will still be needed to evaluate most ground-disturbing development actions because errors of inclusion and exclusion are likely for all but the most detailed site specific studies.

2.2.2 Alluvial Fans

Natural watershed and channel processes, forest management, roads, utilities, agriculture, and residential development can all reduce stability of valley wall slopes and streams upstream of alluvial fans. This in turn increases the natural tendency of floods to deposit sediment and change channels on alluvial fans. Clearing and excavation on alluvial fans can also alter channel migration and flooding areas. The soil strength, changes to rainfall-runoff response, and drainage patterns influence the degree and extent of instability and the subsequent occurrence of valley wall landslides and erosion. Landslides and erosion increase sediment supply and channel migration along the channel and on the alluvial fan, resulting in increased probability and magnitude of debris flows, large floods, and sediment deposition on the fan. Even moderate sized floods from an undisturbed basin can shift the main or side channels across most or all of an alluvial fan.

Not all portions of an alluvial fan are equally active at any given time, and it is difficult to identify or predict which area of an alluvial fan may be active. Relatively recent activity on one portion of a fan is no guarantee that other portions are inactive. For this reason, development on alluvial fans can be problematic and protective dikes and channel dredging may be required in an attempt to protect roads, bridges, and other structures. These measures are typically aimed at keeping the floods and debris flows on one portion of the fan.

Development (including road construction, logging, and even sparse residential development) in watersheds that feed alluvial fans increases the rainfall-runoff response of the watershed. This leads in turn to increased frequency, magnitude, and duration of flood peaks in the small valley wall swales and creeks, as well as the main valley-bottom creek. Vegetation clearing and addition of ditches can concentrate the increased storm runoff and intercept shallow groundwater runoff. Incision and bank slumps occur more often, making the valley walls and channel banks less stable and more prone to increased bedload sediment transport and debris flows. Stormwater detention to reduce runoff is required for most urban and suburban development, but has rarely been used for logging, rural roads, or sparse residential development. Dense developments typically detain only a small part of the increased stormflow, so the hillslopes and channels still adjust to flow changes. Consequently, existing or proposed development is more at risk of flooding, increased deposition, and channel activity on downstream alluvial fans (Booth 1989; Booth et al. 1999; Burgess et al. 1998; Konrad 2000, 2003).

Fixing the channel in one portion of the fan is often motivated by placement of a bridge, culvert, or other structures. Building roads across alluvial fans involves placement of culverts or bridges that assume a static stream position that is unrealistic for the dynamic nature of alluvial fans and motivates regular dredging of the sediment and LWD that builds up in the channels on an alluvial fan. Intermittent dredging following a moderate or large depositional event, or a number of smaller ones, does not guarantee adequate storage for the next floods and deposition events in the channel. A large flood can still overwhelm the area provided for sediment storage, ultimately sending the floodwaters or channel in alternate directions across the fan.

2.2.3 Channel Migration

Development affects channel migration in a number of ways by modifying watershed and channel condition. Encroachment into the channel migration zone places facilities in the way of stream changes. Along some portions of streams, channel migration occurs gradually over many years; in others it can occur rapidly during high flows or floods when residents are often on-guard from rising waters and flood warnings. Consequently, property damage and not public safety is the primary hazard from channel migrations. Channel migration is a natural and ongoing process that builds and constantly changes the channel and floodplain. Streams by their very nature are always changing in balance to water, sediment, LWD supply, and streambank and channel conditions. However, development patterns typically develop as if streams are static and do not change (Brooks 1988; Petts 1989). This has motivated extensive diking and armoring of creeks and rivers in part to stop channel migration and channel changes. When these control measures fail they can pose a risk to residents who may assume the structures are secure.

Construction of dikes, bank armor, constrictions like bridges and culverts, and river training works can reduce or stop channel migration. These protection works often lead to changes in bank erosion, sediment transport and storage, and channel migration up- and downstream of the modified areas. This causes more land losses or requires more protection measures. Protection projects often confine the channel and floods to a much smaller width, which can cause channel changes such as deposition or incision.

The natural tendency of channels to change is also influenced by increased runoff and/or bedload sediment supply from landslides, large storms, clearing, logging, roads, agriculture, and other development actions. Increased stormflow runoff is concentrated in creeks and rivers, causing increased frequency, magnitude, and duration of flood flows. This in turn causes changes in the rate and amount of incision, deposition, increased bank erosion, and related channel migration.

Migration rates are often further increased by clearing of trees along stream banks and in the channel migration zone. Removal of streambank trees and channel dredging removes LWD and jams of trees that provide bank protection, store sediment in the channel, and provide important features for aquatic habitat. Dense streambank and overbank vegetation slows water velocity, leading to sediment deposition. When natural or managed vegetation cover is removed or modified, erosion often results (Bennett and Simon 2004). For example, one of the more effective ways to reduce bank erosion is to add log jams or rock points spaced along the eroding streambank. This diverts the main flow energy away from the bank. Removal of trees and dense vegetation from the channel migration zone reduces the stream’s supply and replenishment of LWD, and impacts other streambank and channel buffer functions. River processes and aquatic habitat conditions depend on the ability of the river to change and form on its own. These functions are hampered by increased stormwater runoff, channel confinement and bank armoring, dikes, or other projects designed to reduce channel migration.

2.2.4 Seismic Hazards

Human actions have no influence on the likelihood of occurrence, timing, or severity of a seismic event. Avoidance of high-risk hazard areas like high landslide hazard areas or lakeshore flood zones are among the few options for most structures. Building on fills that are not adequately engineered, or on deltas and loose alluvial deposits around local lakes, puts structures and residents at risk from large waves that are generated from submarine or shoreline slumps. Fuel and hazardous materials storage facilities and pipelines are at considerable risk during a seismic event, posing a danger to public safety. Planning and appropriate siting of these facilities should be an important part of risk reduction.

2.2.5 Volcanic Hazards

Human activities do not influence volcanic events, but volcanic hazards greatly influence us (Schuster 1989). During an active period of a Cascade volcano there can be many small steam and ash explosions or dome building events that make the immediate area around the mountain dangerous. Larger eruptions or debris flows are not as common but do occur. The most effective response to these risks is public education, emergency planning and preparation to allow evacuation of high and moderate hazard areas and not locating critical structures in high hazard areas.

2.2.6 Mine Hazard Areas

Areas over mines can experience subsidence and slumping from collapse of mine tunnels, entrances, or air shafts. Without checking maps, property owners may not even know if mine workings underlie their land. Known mine entrances and vents should be properly stabilized and closed to minimize risks.

3. GAP ANALYSIS AND REGULATION OPTIONS

As stated in Growth Management Act (GMA) guidelines, the assessment of geological hazards is approached from the perspective of risk:

Counties and cities should classify geologically hazardous area as either:

(i) Known or suspected risk;

(ii) No risk;

(iii) Risk unknown - data are not available to determine the presence or absence of a geological hazard. [WAC 365-190-080 (4)(b)]

The GMA guidelines for geological hazards provides the following comment on risk:

> *Geologically hazardous areas include areas susceptible to erosion, sliding, earthquake, or other geological events. They pose a threat to the health and safety of citizens when incompatible commercial, residential, or industrial development is sited in areas of significant hazard. Some geological hazards can be reduced or mitigated by engineering, design, or modified construction or mining practices so that risks to health and safety are acceptable. When technology cannot* ***reduce risks to acceptable levels****, building in geologically hazardous areas is best avoided. This distinction should be considered by counties and cities that do not now classify geological hazards as they develop their classification scheme* [WAC 365-190-080 (4)(b)] (emphasis added).

Existing Lewis County Comprehensive Plan Policies address risk in the following objectives and policies:

> *Objective NE 1 Encourage development in areas with few environmental hazards in order to minimize both the loss of natural resources due to urbanization and* ***the loss of capital investment and life*** *due to natural disasters.* (emphasis added)

> *Policy NE 4.1 Preserve hazardous areas (subject to geologic and flood hazards) as open space wherever possible.*

In addition, the existing Lewis County critical areas regulations contain direction on minimizing risk in the following criteria:

> *17.35.920.(5)(f)(i) An undisturbed buffer adequate to assure that risk of slide is reduced to levels acceptable to geotechnical engineers shall be required for all structures intended for human user occupation. The buffer shall be measured on the surface and is required from the top, toe, and along all sides of any existing landslide or erosion hazard area.* (emphasis added).

In order to accurately characterize risk for geological hazards fundamental physical geologic processes need to be identified. In addition, secondary impacts may also need to be considered. Failure to consider the entire physical and social environment that relates to a project often results in significant public costs. For example, dikes or dredging may result in channel changes, and drainage from roads could result in additional runoff increasing the size and number of floods. Therefore, modern approaches for evaluating and regulating development tend to include comprehensive ways of assessing and mitigating land development risks.

Geologic hazard assessments can be used to rank the relative risk associated with different hazardous areas. Development limitations, building or other hazard constraints, and guidelines can be applied to the moderate and high risk areas. Not all geologic processes are influenced or controlled by human activities. However, some natural geologic processes such as erosion, landslides, and river channel migration can be exacerbated by land use practices such as shore defense works, dredging, drainage modifications, road construction, vegetation clearing, and grading.

The options for regulating geological hazards vary primarily in the degree of specificity of regulation. In general, the greater the specificity the more likely risk will be avoided or reduced.

Each option addresses the following criteria:

- Designating and classifying the hazard areas
- The information needed to assess risk on a specific site

The options for avoiding risk generally range from:

- Allowing individuals to determine the risk they are willing to accept.
- Specifying restrictions on the types of developments; largely aimed at reducing exposure to uses involving risk to human life, especially large groups in uses such as schools or assembly facilities. The most successful and ultimately least costly protection from geologic hazards is often avoidance of known hazardous areas. This includes activities on adjacent areas that may result in an increased failure hazard that moves off site, down slope, or downstream.
- Reducing the exposure of occupied buildings through requirements for building setbacks, buffers, and vegetation management; as well as adherence to building codes; and development of monitoring and warning systems, evacuation plans, and recovery plans.
- Reducing secondary effects to other resources, such as fish, through limiting activities that result in discharge of materials into water bodies or other effects that may damage habitat.

The extent to which these measures are included in the County's existing regulations are noted below, together with other options.

3.1 LANDSLIDE HAZARD AREAS

This section addresses landslide hazards including translational slides, rotational slides, debris flows, and soil creep. Alluvial fan hazards also include landslide hazards, however, because they also include channel processes, the techniques for alluvial fan hazard avoidance are sufficiently different to recommend an alternative regulatory approaches discussed in Section 3.3.

3.1.1 Designation and Classification

Designating and classifying landslide hazard areas are generally based on identifying factors that affect landsliding that include relief, slope, slope shape, soil depth, aspect, geologic materials, precipitation, vegetation history and condition, roads and other ground disturbance, and other factors (Dragovich et al. 1993; Selby 1993; Montgomery et al. 1998). These factors identify areas at higher risk of landslides and some can be identified from maps while others require field investigations by a qualified professional. Even with site assessment, considerable uncertainty can remain.

A common approach used to identify landslide risk areas is to classify hazard based primarily on slope gradient and shape or the presence of existing slides. Areas with gentle slopes are often considered to have a lower risk of landslides. Slope gradients less than about 15 percent are typically classified as low hazard. Landslide risks in low-slope areas are typically related to deep-seated rotational slides or run-out from slides generated in nearby steeper terrain. In Lewis County, one type of low-slope landslide hazards is on deltas and unconsolidated fill or alluvium along lakeshores.

Steeper areas have more landslides because of the greater slope, more active soil processes, and surface and subsurface water conditions (Dragovich et al. 1993; Baum et al. 1998; Chatwin et al. 1991; Dietrich et al. 1992; Gerstel and Brunengo 1994; Swanston 1997; Thorsen 1989). Slopes steeper than about 35 percent typically have more landslides and are classified as higher risk landslide hazard areas for clearing and grading. Slopes steeper than about 60 percent present an elevated slide risk with road building or tree cutting (Swanston 1970, 1978, 1980, 1981, 1989, 1997).

Slope shape also influences the potential for slides. Concave areas tend to concentrate surface and subsurface water and accumulated thicker unconsolidated soils that are more prone to slides whereas straight and convex slope areas tend to disperse water reducing but not eliminating the risk of slides.

In a landslide study of the Tilton River, Lake Creek, Mineral Creek areas of Lewis County, slope gradient was found to be a dominant factor controlling the location of landslides (Dragovich et al. 1993). Shallow slope and road landslides were commonly initiated on slopes greater than 25 degrees (47 percent slope), and can generally be expected on slopes over 35 degrees (70 percent slope). Deep-seated landslides were found on slopes as low as 7 degrees (12 percent slope) but most field measured slopes of large deep-seated landslides were between 21 and 45 degrees (38 to 100 percent slope). They found that most slopes over 35 degrees (70 percent slope) were susceptible to rapid soil movement. Local Lewis County studies and regional information indicates slopes steeper than 35 degrees (70 percent slope) are inherently unstable, given long spans of time (Dragovich et al. 1993).

Options for Designation and Classification of Landslide Hazards

Existing Classification System

Designation of landslide hazards are addressed in LCC 17.35.920 and include the following:

(i) Areas of historic failure, such as areas designated as quaternary slumps, earthflows, mudflows, or landslides on maps published as the United States Geological Survey or Department of Natural Resources Division of Geology and Earth Resources;

(ii) Areas which are rated as unstable due to characteristics of the earth material and topography;

(iii) Any area with all of the following:

(A) A slope greater than 15 percent, and

(B) Hillsides intersecting geologic contacts with a relatively permeable sediment overlying a relatively impermeable sediment or bedrock, and

(C) Springs or ground water seepage;

(iv) Slopes that are parallel or sub-parallel to planes of weakness;

(v) Slopes having gradients greater than 80 percent subject to rockfall during seismic shaking;

(vi) Areas potentially unstable as a result of rapid stream incision and streambank erosion;

(vii) Areas located in a canyon, on an alluvial fan, or presently or potentially subject to inundation by debris flows or catastrophic flooding;

(viii) Areas included in the Slope Stability Study of the Centralia-Chehalis Area, Lewis County, Washington by Allen J. Fiksdal, Department of Natural Resources, Division of Geology and Earth Resources, 1978: Areas mapped as "unstable," "landslides," and "old landslides" (if slopes are in excess of 30 percent);

(ix) Areas located outside the study area on the Slope Stability Study of the Centralia-Chehalis Area, regardless of slope, that are mapped as "landslide debris" in the following Open File Reports and maps at a scale of 1:100,000 available from the Washington State Department of Natural Resources, Division of Geology and Earth Resources:

(A) Open File Report 87-11, Centralia Quadrangle, by H.S. Schasse, 1987,

(B) Open File Report 87-16, Mount Rainier Quadrangle, by H.S. Schasse, 1987,

(C) Open File Report 87-4, Mount St. Helens Quadrangle, by W.M. Phillips, 1987,

(D) Open File Report 87-8, Chehalis River and Westport Quadrangle, by R.L. Logan, 1987,

(E) Open File Report 87-5, Mount Adams Quadrangle, by M.A. Korosec, 1987,

*(F) Open File Report 87-2, Astor*ia and Ilwaco Quadrangle, by T.J. Walsh, 1987.

Criteria (i) through (vii) are identical to some of the Washington State Department of Community, Trade and Economic Development (CTED) Example Code (CTED 2003).

Options for Classification Systems

Additional criteria in the CTED Example Code that could be included in Lewis County regulations include:

- Slopes greater than 40 percent with a vertical relief of ten or more feet. This criteria is partially addressed for the Centralia-Chehalis Area in the Allen J. Fiksdal study referenced, but is not generally provided for in the rest of the County.
- Areas at risk from snow avalanches.
- Areas designated with soils as having a "severe" limitation for building site development.

There are several other criteria that could be used for designating landslide hazard areas, including:

- Slopes in the nearby foothills show landslide hazards perpendicular to planes of weakness, as well as parallel
- Unconsolidated deposits around lakes, especially delta deposits. Deltas and some shore deposits around lakeshores consisting of loose saturated materials often have steep or undercut surfaces. Shaking from small local or large regional earthquakes can cause slumps in these deposits, which can be dangerous to shore facilities. This is discussed further under the Seismic Hazard Areas section below.

An additional option is to distinguish different standards between moderate and high hazard areas, generally allowing greater flexibility in areas with lower hazards. Many counties and cities list some subset of the general landslide controlling factors with their landslide hazard codes and often further classify landslide hazard criteria based on slope classes. Common is the use of two hazard classes based on slope (15 to 35 percent and >35 percent). The present Lewis County landslide code has some criteria in the range of 15 to 30 percent slope and is inline with hillslope studies and code requirements in the region. The State's model code uses a similar steep slope criterion (40 percent). Using two classes and starting at the 15 percent slope gradient provides a better understanding of site conditions and includes more of the slope range where slides are typically an issue.

Additional approaches for identifying and classifying landslide hazard areas include models and new surface mapping methods. Research has shown that shallow landslide hazard models can improve estimates of landslide-prone areas by using multiple risk factors in addition to slope (Montgomery and Dietrich 1994; Montgomery et al. 1998). More reliable mapping of landslide risk areas can be achieved by using computer models that classify risk based on slope gradient and shape; surface and subsurface geology and soils; and valley and channel confinement and gradient. These models can be further improved by including site factors at existing slide areas. Site-specific analysis would still be needed for evaluation of land use proposals located in moderate and high risk slide areas identified with the area wide models.

A recent mapping technology called LIDAR imaging uses aerial laser ranging to map the earth surface. It often shows landslides and fault scarps that could not easily be seen using stereo aerial photographs. This is particularly useful in areas with dense forest cover for locating existing and ancient slide areas. The County should set up the landslide code and related sections so areas not presently inventoried by existing studies can take advantage of new, more detailed, and updated landslide inventories and models. A detailed surface geology map for the main Lewis County jurisdictional areas, combined with topography, soils, land use and other data, would help in the first-level screening or modeling for landslide, erosion, seismic, and related hazard areas. A county-wide map would also provide a context for site-specific mapping conducted for development proposals. Site-specific mapping should be a part of every development permit.

It is important to recognize that the indicators discussed above provide guidance as to the likely presence of landslide hazards, but do not conclusively establish the existence or extent of a hazard.

Options for Regulations to Address Risk of Landslide Hazards

Existing Regulations

Development standards are included in the existing code in LCC 17.35.920(5) and include:

(a) Grading.

(i) Clearing, grading, and other construction activities shall not aggravate or result in slope instability or surface sloughing;

(ii) Undergrowth shall be preserved to the extent feasible;

(iii) No dead vegetation (slash), fill, or other foreign material shall be placed within a landslide hazard area, other than that approved for bulkheads or other methods of streambank stabilization under the shoreline master program or if such fill is consistent with authorized activities specified in a geotechnical report;

(iv) Minimize ground disturbance to the extent feasible.

(b) Ground Surface Erosion Control Management.

(i) There shall be minimum disturbance of vegetation in order to minimize erosion and maintain existing stability of hazard areas;

(ii) Vegetation removal on the slopes of banks between the ordinary high water mark and the top of the banks shall be minimized because of the potential for erosion;

(iii) Vegetation and organic soil material shall be removed from a fill site prior to the placement of clean earthen material;

(iv) Vegetative cover shall be reestablished on any disturbed surface to the extent feasible;

(v) Groundcovers (approved geotechnical controls) such as filter fabrics, rip-rap, etc. shall be placed on any disturbed surface to the extent feasible.

(c) Drainage.

(i) Surface drainage, including downspouts, shall not be directed across the face of a hazard area. If drainage must be discharged from the top of a hazard area to its toe, it shall be collected above the top and directed to the toe by tight line drain, and provided with an energy dissipative device at the toe for discharge to a swale or other acceptable natural drainage areas.

(ii) Storm water retention and detention systems, including percolation systems utilizing buried pipe are strongly discouraged unless a geotechnical assessment indicates such a system shall not affect slope stability and the systems are designed by a licensed civil engineer. The licensed civil engineer shall also certify that the systems are installed as designed.

(d) On-Site Sewage Disposal System Drainfields. For the purpose of landslide or erosion control, the on-site sewage disposal system drainfields shall be located outside the hazard area and its buffer, unless otherwise justified by a qualified geotechnical engineer. The septic system drainfield must be in compliance with the regulations of the Lewis County health department or its successors.

(e) Lot Size. For the purpose of determining lot sizes within hazard areas, the administrator shall review available information, including any required geotechnical assessments and make a decision on a case-by-case basis based on the reports.

(f) Buffers.

(i) An undisturbed buffer adequate to assure that risk of slide is reduced to levels acceptable to geotechnical engineers shall be required for all structures intended for human user occupation. The buffer shall be measured on the surface and is required from the top, toe, and along all sides of any existing landslide or erosion hazard area.

(ii) The buffer shall be clearly staked before any construction or clearing takes place.

(g) Design Guidelines.

(i) Structures should be clustered where possible to reduce disturbance and removal of vegetation.

(ii) Foundations should conform to the natural contours of the slope and foundations should be stepped/tiered where possible to conform to existing topography of the site.

(iii) Roads, walkways, and parking areas should be designed with low gradients or parallel to the natural contours of the site.

(iv) Access should be in the least sensitive area of the site.

(h) No critical facilities shall be constructed or located within an erosion or landslide hazard area. [Ord. 1170B, 2000; Ord. 1157, 1998; Ord. 1150 § 4.6(B), 1996]

The standards for grading, erosion control, drainage, on-site sewage disposal, lot size and building location and design all address features of human alteration of sites that typically increase landslide risks. These standards are likely to be generally beneficial. In most cases they are also applicable to erosion control, addressed separately below.

The nature of alluvial fan hazards is somewhat different than for translational slides, rotational slides, debris flows, and soil creep. The techniques for hazard avoidance are different enough that an alternative regulatory approach is recommended below.

The criteria that: “Clearing, grading, and other construction activities shall not aggravate or result in slope instability or surface sloughing” provides a presumption that these activities are generally allowed in landslide hazard areas. The general scientific record would indicate that preservation of vegetation is beneficial in reducing landslide hazards, especially for translational slides, debris flows and soil creep. As indicated above, clearing and grading reduce or remove the interception of precipitation stormwater provided by vegetation, reduces or removes the strength that roots provide to the soils on river banks and steep slopes and may result in excess surface runoff with concentration into rills. The existing code standard depends on the quality of administration, and particularly the methods of assessment relied upon to demonstrate whether or not grading and other activities will or will not aggravate or result in instability. This can be is scientifically problematic. The provision also has the potential for inconsistency with the buffer requirement in item (h).

Lewis County standards that directly address risk avoidance from placement of development include (f) addressing buffers, and (h) which prohibits “critical facilities” within an erosion or landslide area. The buffer requirement in (f) applies only to structures intended for human habitation. This provides protection of human health and safety for residents, but does not address other uses where people may work or assemble. The provision (h) for critical facilities is protective of facilities such as schools, hospital, and emergency response facilities. The provision, however, does not address the adverse impacts landslides may have on water resources and other ecological functions, nor does it define the types and scale of critical structures it applies to.

The provisions for buffers presume a process to evaluate risk and establish buffers that is not specified. The standard “that risk of slide is reduced to levels acceptable to geotechnical engineers” presumes that there is a professionally accepted standard in general use. Referring public policy to such a presumed standard is problematic in terms of predictability. The fact that Washington State does not license geotechnical engineers separately from other Professional Engineers leave the decision of competence to practice in this area to the discretion of individuals. Given these factors, there is likely to be a range of judgments as to what is acceptable risk among practitioners.

For effective administration, applicable scientific expertise is applied to decisions called for in:

(a)(i) Clearing, grading, and other construction activities shall not aggravate or result in slope instability or surface sloughing; and

(f)(i) An undisturbed buffer adequate to assure that risk of slide is reduced to levels acceptable to geotechnical engineers shall be required for all structures intended for human user occupation. The buffer shall be measured on the surface and is required from the top, toe, and along all sides of any existing landslide or erosion hazard area.

In order to assure that the existing code brings adequate scientific analysis to bear in meeting the standards, the provisions should specify minimum reporting and performance standards for practitioners, content requirements for technical studies and specific criteria for acceptable risk.

Optional higher levels of regulatory specificity

Alternate approaches to regulation of geologically hazardous areas that provide higher levels of protection with specific standards to reduce the level of protection based meeting specific standards can be employed in cases where the public desires to reduce risk to a greater extent.

Protective Approach

An approach commonly used in risk reduction for geological hazards is to:

- Avoid disturbance in hazard areas as a base case;
- Provide standard buffers that provide a margin of safety
- Allow specific activities in hazard areas based on specific conditions that may include:
- Lack of siting alternatives;
- Specific provision for alternative approaches based on detailed studies by qualified professionals with clear criteria and performance standards.

Because small landslide areas and many erosion areas can be modified with structures and other construction methods, code options should remain adaptable. This places considerable responsibility on site-specific studies by qualified professionals, design approaches tailored to site conditions, a review processes providing clear criteria, construction methods developed by qualified professionals, and effective monitoring.

Some jurisdictions divide the slopes into three or more hazard levels with more restrictions and buffers applied to the higher-gradient slopes. Building setbacks, vegetated buffers, and drainage guidelines are commonly used to reduce hazards from landslides or in landslide run-out areas.

An example of code provisions that allow modification of landslide hazard areas may include the following:

Alteration of a landslide hazard area may be allowed by the Administrator only under the following conditions:

1) A geotechnical study performed by a qualified professional demonstrates that:
   a) The site is stable under existing conditions based on a plane of failure analysis with a factor of safety of 1.5 under seismic conditions for unconsolidated deposits or other factor of safety relevant to the type of development;
   b) Alteration of vegetation will not increase the probability of slope failure; and
   c) Proposed grading, excavation or structures will not increase the probability of slope failure and construction of facilities to reduce risk, such as drainage systems, are effective in the absence of mechanical systems such as pumping or dewatering facilities and do not require long-term maintenance.

2) The potential for additional erosion on the slope and deposition downslope can be controlled by feasible measures.

3) The development will not increase the risk of slope failure on adjacent properties.

4) Alteration will not adversely impact other critical areas or their associated buffers, such as wetlands, wildlife habitat areas, frequently flooded areas and critical aquifer recharge areas.

A variation of this approach would apply an additional standard of avoidance for new development and allow alteration only for existing lots or parcels where design options for avoidance are not feasible. In this case, the standard provision would not allow the creation of new lots or new commercial or industrial development that would pose or exacerbate a foreseeable geological risk to people or improvements during the life of the development. (This standard is included for areas under Shoreline Management Act jurisdiction in guidelines in WAC 221(2)(c)(ii)(B), however Lewis County is not required to update its Shoreline Master Program at this time.)

Impacts on erosion and sedimentation are an additional consideration for landslide hazards regulations. The impacts of increased erosion are present even if slopes are stable, and are of additional concern when surface waters are nearby. .An additional consideration for landslide hazards also associated with erosion hazards is the desirability of avoidance to reduce erosion/sedimentation impacts.

Buffers

Buffers are an additional technique typically used to provide a factor of safety to development in the vicinity of landslide hazards. The buffer recommendation in the CTED Example Code is "equal to the height of the slope, or 50 feet, whichever is greater." This standard is generally based on observation of small landslides that seldom propagate a substantial distance. This distance varies depending on the style of failure, degree of saturation, and slope morphology. For instance, rotational and translational failures are often limited to one or two times the slope height (Iverson 1997). Landslides originating high on a slope or within a confined ravine may become saturated and turn into a debris flow. Debris flows behave as a fluid and may travel for extended distances before coming to rest (Iverson 1997; Iverson et al.1997). For very steep slopes, such as those resulting from rapid stream incision or bank erosion, the eventual plane of repose is likely to be at a 2:1 or flatter slope. In situations such as this, a setback measured from the toe of slope provides a better assurance of risk avoidance.

It is important to note that the factors that influence geologic hazards vary greatly from site to site. Site specific investigations are the most reliable method to characterize risk and develop an appropriate buffer or setback. The cost of geologic investigations, however, may be a significant factor in the ability of a land owner to pursue a project. In addition, even with professional assessment, uncertainly and risk remain. Prescriptive buffers must be regarded as providing a certain margin for reduction of exposure to risk, but are not foolproof.

The approach to buffers also may differ according to the density of development. In rural areas with lot sizes of 5 acres or greater, avoidance may reduce most risks and also provide land owners with considerable flexibility for locating uses. In urban areas, small lot sizes and the risks to infrastructure such as streets and utilities may warrant site-specific studies on a more routine basis.

A buffer standard that provides a reasonable assurance that most development will be protected from damage (with the option of site specific studies) would include the following:

A buffer shall be established to minimize the risk of property damage, death, or injury resulting from landslides. Buffer requirements shall be determined by the following:

1) Standard buffer areas shall be measured from the top, toe, and edge of the slope hazard area and shall be the greater of the following:
   a) Fifty feet;
   b) Equal to the height of the slope for landslide hazards on slopes between 15 and 40 percent;
   c) Equal to 1.5 times the height of the slope on slopes greater than 40 percent
   d) Equal to 2 times the height of the slope on slopes greater than 50 percent;
2) Buffers may be established by the Administrator based on a specific geotechnical study performed by a qualified professional.
   a) In unconsolidated deposits, the buffer area shall be established based on a plane of failure analysis with a factor of safety of 1.5 under seismic conditions.
   b) For debris flow hazards runout areas shall be assessed by a qualified geotechnical professional and be addressed by using models of debris flow deposition by Benda and Cundy (1990) that are based on channel gradient, confinement, tributary junction angle, and potential for debris dam formation and dambreak failure.
   c) Rockfall conditions shall be assessed by a qualified geotechnical professional.

3.2 EROSION HAZARD AREAS

Determination of areas where erosion potential may present a hazard or deliver sediment to surface waters is based on evaluation of soil type, slope gradient, slope length, vegetation condition, precipitation zone, water conditions, slope position, land use, and other factors. The existing provision of LCC 17.35.920(1)(a) defines erosion hazard areas as those soils designated as having severe or very severe erosion potential in the Lewis County soil survey.

The areas affected are identified in the Soil Survey of Lewis County Area (Evans and Fibich 1987), and can be depicted using County's GIS system. Lewis County does not include soils having a moderate erosion hazard as provided for in the CTED Example Code. Adding moderate erosion hazard soils would be most effective where surface water is downslope. Also note it can generally be presumed that bare soils, whether on construction sites or agriculture fields, will erode depending on the rainfall or wind conditions. The Soil Conservation Service rating is designed to address agricultural practices, especially cultivated crops where soils may be bare for an extended period. The SCS rating is designed to provide guidance as to the type of crops and the type of practices appropriate for different levels or risk.

The Lewis County code provides development standards that are the same for erosion hazards and landslide hazards. In general, they provide for minimizing disturbance; however, it is not clear how that standard is applied. Again, the ability to minimize is dependent on density of development and type of uses. On a large rural parcel, low intensity agricultural activities such as pasture or silvaculture may expose relatively little soil. Low density residential development may result in relatively little disturbance and little impervious surface. In an urban setting, the development at lot sizes of less than an acre is likely to lead to clearing of most of the land for roads, utilities, homesites, and yards, unless clustering or other methods are used to retain specified open space areas with intact vegetation.

The risk of erosion is directly related to the receiving area for displaced soils. There are issues related to loss of soils as an agricultural resource, but the primary concern for erosion is the delivery to surface waters where it can have a variety of adverse impacts on aquatic habitat. The importance of proximity to surface water is recognized to some extent in the existing Lewis County Critical Areas Regulations in the provisions of LCC 17.35.680 to extend stream buffers to include sloping areas with a 50 percent or greater slope and a 25 foot buffer beyond the top of slope.

The existing Lewis County Critical Area Regulations for erosion hazard areas provide some useful guidance, but little assurance of effective control of erosion, especially adjacent to surface waters. The extension of stream buffers to slopes of 50 percent or greater does not provide protection from erosion on less steep slopes that can have a substantial erosion rates.

In addition to the Critical Area Regulations, soil erosion and surface water drainage are commonly administered through review of drainage plans, grading plans, and erosion control plans that are a part of project design, construction, and maintenance. Lewis County reviews clearing and grading related to development through administration of the clearing and grading provisions of the International Building Code. The State of Washington requires a Construction General Storm Water NPDES permit be obtained for clearing or land-disturbing activities greater than one acre. One of the main conditions of this permit is the development and implementation of a site-specific surface water pollution prevention plan.

Because most erosion concerns are so closely associated with drainage control, ground disturbing activities, and landslides; it is recommended that a single Erosion and Drainage Control section be developed for the code. The primary approach should be performance-oriented and included in the design, construction, and maintenance of development sites. In order to increase the effectiveness of the provisions for erosion hazards in the current regulations, several measures would be effective, including:

- Require specific clearing and grading measures, and utilization of BMPs be used and maintained according to the latest edition of the Washington State Department of Ecology Stormwater Manual.
- Require preparation of a Construction Stormwater Pollution Prevention Plan (SWPPP) for larger projects as well as items like construction phasing, wet season work limitations, and inspection and monitoring requirements
- Add seasonal restrictions as additional assurance of reduction of impact for sites near streams. An alternate approach would be to require additional controls and monitoring for wet-season construction projects.
- Specify certified professional training and experience in erosion and sediment control for erosion control plan design and performance inspections and modifications.

Typical erosion regulations are oriented to new construction and may not adequately address erosion control for agriculture, roads, and hobby farms. The County could consider keeping agricultural districts and hobby farms regulated with approaches similar to those provided by the USDA Natural Resources Conservation Service (NRCS) (formerly USDS Soil Conservation Service). The County could also consider adding erosion control guidelines specific to roads and road maintenance. An example of such a program is the “Conservation Program on Agriculture Lands” developed as part of the Whatcom County Critical Areas

Ordinance in 2005. This program provides for development of farm plans on a performance standard basis for agricultural activities.

Optional higher levels of regulatory specificity

Alternate approaches to regulation of erosion hazards can provide higher levels of protection with specific standards. Examples of approaches include:

- Providing a sliding scale of allowable land clearing based on a combination of topography and soils to limit the amount of land cleared or graded for development. This is typically applied to higher density urban development and is often administered in conjunction with clustered development.
- Provide specific design measures for erosion control in subdivision or other development, such as uncleared bands of vegetation on slopes designed to intercept soil particles during the construction phase of development. These areas could be allowed to be cleared after the balance of the site is stabilized.
- Provide for staging of clearing and grading, allowing only a certain percentage of a site to be disturbed prior to stabilization of existing cleared areas.

These measures could be implemented separately or in combination, depending on the sensitivity of sites and the proximity to surface water.

Buffers

Buffer zones with dense vegetation can be effective in reducing sediment delivery to surface waters from surface erosion and is one of several reasons why stream buffers are recommended. To be effective, runoff from drilling needs to be avoided and buffer widths of 150 feet or more are needed.

3.3 ALLUVIAL FAN HAZARD AREAS

Development has been common on alluvial fans because they are outside the main river floodplains, are relatively flat compared to the steep valley walls. These qualities make alluvial fans attractive development sites along the valley edges of Lewis County despite their inherent risk to life, safety and property.

The hazards of building on alluvial fans are not always apparent in humid regions because of dense forest cover and the false impression that the alluvial fans are inactive (Orme 1989). Regulation of development on fans is needed to protect public safety and reduce hazards to public and private resources. It is clear, based on local, regional, and worldwide studies of alluvial fans, as well as local experience, that many large or small alluvial fans can be very dangerous during storms depending on watershed, valley, and channel conditions.

Alluvial fans are only mentioned in the present code under definitions and generally under landslide hazards in LCC 17.35.920 (1)(vii). Alluvial fan hazards are much more complex than the other landslide hazards and involve flood damage, degradation of stream channel and streambank habitat, and development in potential flood, channel migration, and the debris flow hazard zones. The approach in the existing code is inadequate to address alluvial fan hazards.

Prohibiting development in areas subject to alluvial fan hazards is the recommended approach for reducing alluvial fan hazards. In cases where existing development has occurred, hazards sometimes can be reduced with flood forecasting and warning systems. Watershed stormflow, landslide, and debris flow hazard reduction in the watershed can help but is expensive. Often there are different landowners on the alluvial fans and in the upstream basin, each having different management priorities. Dredging and dikes are common approaches that particularly address alluvial fan hazards but have limited long-term effectiveness due to the nature of the hazard. Existing structures can be protected with a cluster of piles that can filter out LWD in debris flows but does not prevent damage from floodwaters and sediment deposition.

Alluvial fans that are more prone to debris flows and dam break conditions can be distinguished from less active fans by analysis of valley confinement and slope models (Benda and Cundy 1990). Portions of alluvial fans with less potential hazards can be estimated, however, these risk assessments require fairly extensive studies (Kerr, Wood, and Leidal 2003, 2004). Based on topographic and watershed conditions, a first-level screening process could be used to help identify higher risk fans in Lewis County. Such a process would employ methods and concepts found in Benda and Cundy (1990); Benda and Dunne (1997); Dietrich et al. (1995); and Montgomery et al. (2003), Kerr, Wood, and Leidal (2003, 2004) and Pelletier et al. (2005).

Given the high level of risk from alluvial fan hazards, it is recommended that:

- A comprehensive classification of alluvial fans be done in Lewis County, to identify the alluvial fan hazard areas.
- Development in alluvial fan hazard areas be prohibited, unless detailed assessment and risk management studies are prepared.
- Once such maps are available, a hazard rating system could be developed to identify the low, moderate, and higher hazard alluvial fans. Detailed studies of developed high-hazard alluvial fans could show the high hazard portions of the fan and help to identify approaches to reduce risk on developed fan areas. The recent western Washington alluvial fan studies by Kerr, Wood, and Leidal (2003, 2004) are examples of the types of alluvial fan assessments that are needed for high-hazard alluvial fans with existing or proposed development. Similar studies in Lewis County would provide estimates of hazard levels on various portions of the high hazard alluvial fans.
- Additional detailed studies for new development on higher risk alluvial fans could be required at the time of application for development permits. However, identifying risk areas on alluvial fans depends on detailed subsurface and surface geologic mapping, watershed, hydrologic, and hydraulic studies. Such studies would require more resources than are typically available to the average landowner. For locations where development commitments have not been made avoidance is the most reasonable long-term approach.
- For areas with substantial existing development, long-term strategies for mitigating damage associated with alluvial fans that have been used in the region include:
  - moving structures out of high-risk areas
  - avoiding new construction in the most hazardous areas
  - reducing upslope hazard conditions
  - using pile filters to help remove logs and large rocks from floods or debris flows
  - building dikes and dredging channels to maintain the channel location

Dredging and dike construction can also be used to increase the channel's capacity to store flood sediment, minimize major channel shifting. Some problems related to safety on alluvial fans are difficult to mitigate because of costs. In addition, common mitigation solutions typically conflict with stream aquatic habitat conditions and formative processes in many creeks.

3.4 CHANNEL MIGRATION HAZARD AREAS

Channel migration is not addressed in current Lewis County Codes. Riverine flood damage is often the result of high water impacts, combined with erosion and deposition from channel migration or shifting. Facilities near the main river or creek channel are typically at greatest risk unless there is bedrock or substantial bank protection. Historic encroachment near or in a channel migration zone motivates bank armoring, dikes, channel dredging, and other measures aimed at forcing the river into a static condition in a narrow area. This approach is often costly, difficult to maintain, has up- and downstream impacts, and adversely affects aquatic habitat.

Channel migration zones often include a portion of the flood-prone area of a river or stream, but in many areas the channel migration zone is smaller but sometimes can be larger than the floodway. Geologic features such as terraces or bedrock banks commonly serve as boundaries to the channel migration zone. Engineered and maintained levees are considered to be the channel migration boundary if they meet approved building standards. Poorly built, abandoned, and undocumented levees are often not substantial enough to limit channel migration or jumping.

Floodway and migration zone development that fails to acknowledge the dynamic nature of rivers has led to a cycle of continuous and costly protection projects using private but mostly public funds. The most basic but least used protection approach is simply to allow adequate room for stream processes. Long-term reduction of shoreline encroachment (over 30 to 100 years) will greatly reduce flood and channel migration damage costs and will allow for restoration of aquatic habitat. Long-term planning needs to account for and work with ongoing stream processes. This will reduce the danger from sudden channel changes, reduce flood and river management costs, and allow for aquatic habitat improvements from protection and maintenance projects.

An example of channel migration regulations developed for rivers are the King County sensitive area rules and guidelines related to alterations within channel migration areas (King County Code Chapter 21A to 24; King County 1999). The King County channel migration regulations are based on estimating the extent of channel changes over the past 100 years or as far back as map or ground evidence can demonstrate. The regulations restrict certain types of development and establish setback buffers based on flood heights and the documented channel changes. Application of the King County rules depends on detailed studies of historic maps, aerial photographs, and field investigations. In some areas the channel migration zone is fairly easy to define because of older terraces or bedrock, but in others the migration zone may not be well defined.

A preliminary study has been performed for the upper Cowlitz; Rainy Creek, and Lower Cispus, however, high, moderate, and low hazard zones have not been estimated. Studies are also needed to identify the boundaries of creek channel migration zones and estimate high risk areas. The same methods used to estimate the migration hazard areas of rivers are used for creeks.

3.5 SEISMIC HAZARD AREAS

Seismic hazards are addressed in the Lewis County Critical Area Regulations through building code requirements for construction. The entire County, and indeed the State of Washington, are subject to earthquakes. Building standards like the International Building Code are varied by building type and are use to help reduce earthquake damage and injuries. Considerable engineering is applied to the design and review of seismic loading on critical structures. Extensive site surface and subsurface mapping and analysis are needed to support foundation and structure design. Being prepared, avoiding high hazard site locations and conditions, and implementing building standards to minimize danger during and immediately following an earthquake, are the main approaches used to reducing seismic hazards. These approaches are currently employed by Lewis County.

Options for higher levels of regulatory specificity

Designation of high risk areas is the first step to imposing higher levels of regulation. Delineation of ground-shaking and ground-failure hazards by mapping and site-specific prediction analysis is an important step in the process of reducing the effects of earthquakes (Rogers et al. 1998). Ground-shaking and ground-failure hazard maps are valuable in siting or relocation of local government emergency facilities, developing land use policies, and making urban renewal decisions (Rogers et al. 1998). Seismic ground-shaking and ground-failure hazards are estimated based on:

- analysis of regional historic earthquake records
- location and physical properties of geologic deposits
- topography and sediment thickness
- basin geometry
- water conditions
- analysis of factors affecting the attenuation of ground motion
- seismic and geologic mapping of faults
- mapping and analysis of site-specific geologic conditions (Rogers et al. 1998)

Preparation of seismic hazard maps based on this level of information is far from complete in the Pacific Northwest (Rogers et al. 1998). Currently and in the near future, decisions will need to be made based on applying a factor of safety to the best available information.

Areas with greater damage risk, such as shorelines, thick unconsolidated soils, or steep slopes could be screened on a broad scale. This would only be a first-level screening, however, and would miss numerous isolated or poorly mapped areas, potentially under-representing risk. With existing soils and geology maps, only general zones of higher risks can be classified. As detailed surface and subsurface geologic mapping and analysis become available in the future, it may be possible to differentiate hazard zones more precisely. This type of mapping is usually done only for critical structures. Widespread mapping is accomplished at a slower pace, as it is conducted by graduate students or through regional research by the USGS and others.

Seismic hazard studies specific to Lewis County and a detailed map of the surface and subsurface geology would help further identify faults, liquefaction, landslide, and ground shaking hazard areas. This may or may not provide additional development latitude compared to less-specific regional information. No single factor (e.g., local fault locations or liquefaction potential) fully defines seismic risk. Many other factors influence seismic risk, for example, the shape of the consolidated bedrock below the valley or deep thrust faults.

The County could be segmented into a few seismic hazard classes, but current studies should be updated before fully committing to that approach. Consequently, the most supportable approach for the present and near future may be to base building standards on the type of building or development, and to apply the same standard countywide.

Although some areas face a greater risk than others, all of Lewis County is potentially at risk of significant earthquake damage as the present code notes. To respond to our changing understanding of the seismic risk in this region, the County should continue to link regulations to building standards and change to the International Building Code and relevant local U.S. Geological Survey (USGS) or other agency documents and studies. As codes and studies change, the County code should also change.

As a preliminary step, the County can identify the depositional basins containing unconsolidated saturated deposits by using existing geological studies in combination with the County soils survey for high risk liquefaction areas. Depositional basins are high hazard areas because they can amplify the ground-shaking energy and disturbance and saturated loose surface soils are subject to risks of liquefaction during an earthquake.

3.5.2 Risk Management of Seismic Hazards.

Three main approaches are often taken where earthquake are inevitable:

(1) Fail-safe approach

(2) Safe-failure approach

(3) Combination approach

A fail-safe design is intended to survive shaking with little or no damage. This approach is often attempted with very critical structures. The safe-failure approach is used where the design can not practically be built to survive shaking or because the structure is less critical and can be allowed to fail. For the combination approach, fail-safe designs are attempted up to a practical design level and safe-failure aspects are included to reduce the hazard when shaking exceeds design standards.

The application of these approaches generally varies according to the population exposed to risk. The fail-safe approach is most often applied to facilities where a large number of people would be exposed to risk. These include schools, public assembly, hospitals, nursing homes and similar uses. The fail-safe approach is also used for emergency response facilities, or facilities with a large risk exposure such as areas where hazardous materials are used or stored. A safe-failure approach is generally applied to homes and low-occupancy buildings.

Existing structures can be at least partly retrofitted to reduce damage. Retrofitting existing critical facilities for safe-failure typically incur the greatest costs and engineering challenges. For example, many bridges or oil and gas facilities were not originally built to survive damages caused by shaking or waves. Such facilities face greater challenges in preventing potential large spills or failures of high use routes. Consequently, new regulations should consider the International Design Codes for new construction, as well as guidelines and programs for retrofitting existing facilities.

Minimum regulations to help reduce injury and damage should be implemented countywide, and should not be limited to any one land type. Building standards for seismically active areas are generally based on region-wide tectonic and seismic studies from the past few decades. Estimates of the likely vertical and horizontal accelerations and displacement are calculated and used as the basis for static and dynamic design for various types of structures. In areas of high risk, upgrades and retrofits are common for the numerous structures built using older standards. Building standards are incorporated in the existing Lewis County codes and generally provide a safe-failure approach that applies to all types of exposure.

The State's CTED model seismic hazard code provides a different level of protection for different types of facilities. The standards are fairly limited, but provide a general approach that could be adapted for Lewis County. For example, the State's list of allowed activities would likely require additional detail and categories for Lewis County. Experienced geotechnical engineers, geologists, engineering geologists, and structural engineers should perform analyses of seismic conditions. Most construction would be covered by standard building codes specifically dealing with seismic hazard reduction. Critical and specialized structures would receive special analysis and design conditions that exceed standard code guidelines. This is particularly important for industrial facilities in Lewis County. Safe-failure of these large facilities is important to the health and safety of workers and local residents. As an additional non-regulatory element, the County could use a process to screen for structures that need retrofits, and develop programs to motivate appropriate retrofits.

Sites with greater damage risk, such as depositional basins containing unconsolidated saturated deposits, can be subject to an additional level of site analysis and structural review. For areas subject to liquefaction, detailed site analysis and evaluation of mitigation alternatives should be required. The initial mitigation option considered should be avoidance. If avoidance is not appropriate, a variety of other measures may be developed by qualified geotechnical specialists depending on site conditions. These measures may include deep foundation systems that would transfer loads to dense soils beneath liquefiable deposits, ground improvement measures to reduce liquefaction potential through reducing water saturation, or containment measures to reduce the hazard of lateral spreading. The complexity of conditions would mandate a case-by-case assessment.

Areas subject to liquefaction should require more stringent standards for location of critical facilities that concentrate a large number of people such as schools, or facilities that are essential in emergency situations.

Estimates of seismically induced landslide and run-out hazard areas are based on slope gradient and shape, materials, probabilities of moisture conditions, and the presence of past slope failures. Seismic shaking is only one of many factors influencing landslide hazards. Linking the seismic and landslide hazard regulations would be a reasonable approach. Seismically induced landslide hazards could be addressed in the landslide section of the code and simply mentioned in the seismic section, or vice-versa. In a similar way, lakeshore wave and seiche hazard areas could be addressed in the seismic regulations and mentioned in the landslide code.

Because of the risk of significant earthquakes, mapping and analysis for each development is needed to establish site-specific seismic loading design criteria. Specific seismic regulations may be needed for the highest risk zones such as landslide-prone slopes and run-out areas, lakeshore seiches, areas with shallow loose saturated soils, and areas over deep unconsolidated sedimentary basins. Each development should be required to provide site-specific information to support the general classifications and selected design criteria.

3.6 VOLCANIC HAZARD AREAS

Lewis County is most influenced by Mount Rainier, Mount Adams, and Mount St. Helens. Some of the volcanic hazards are primarily located in the remote portions of Lewis County but debris flows, mudflows, lahars, volcanic induced outburst floods, and tephra fall extend further from the volcanoes.

3.6.1 Hazard Zone, General Evacuation Strategies

The present approach for volcanic hazard mapping in Washington State and other regions is to define hazard zones around volcanoes and to monitor for changing activity of the Cascade volcanoes. Volcanic hazard zones are based on historic and ancient occurrence of volcanic activity, as described by geologic mapping around the volcano and in surrounding valleys, combined with debris flow run-out modeling. Hazard zones are estimated for the main risks, including blast zone, pyroclastic flows, debris flows (lahars), ash fall, and outburst floods. When monitoring indicates an elevated risk, the public and agencies are warned. The decision of whether to evacuate some or all individuals in an area is made by the responsible public officials.

Many of the most damaging effects of volcanic eruptions can be particularly mitigated if adequate monitoring is in place (Ebert 2005). Presently, monitoring of the Cascade volcanoes has a number of gaps including a lack of an in-place early warning system and adequate instrumentation on many volcanoes, and lack of continuous monitoring (Ebert 2005).

Overall, the main volcanic hazard zones have been roughly defined based on studies conducted in the 1990s. Additional studies and monitoring of all the local volcanoes and refinement of hazard ratings are needed. Currently, most of the present funding goes to Mount St. Helens monitoring. Additional funding would be required to conduct studies of the Lewis County region. These studies are needed to identify hazard areas, provide more data to estimate the frequency of volcanic events, and perform long term monitoring to gain understanding on how each mountain works. The Lewis County Volcanic Hazards code should be adaptable to the changes that will result from additional studies and analysis.

To define volcanic hazards, Lewis County uses the USGS Report 91-4028 relating to mudflow from failure of the Spirit Lake Debris Dam and USGS Report OP-90-0385. The County also cross-references to the criteria in RCW 36.70A for volcanic hazards. The latter is non-specific geographically. In order to utilize all available studies, it is recommended the following additional resources and future updates be used to identify volcanic hazard areas:

3.6.2 Hazard Classification with Avoidance or Rapid Evacuation Strategies

A hazard classification approach is based on the premise that our knowledge of volcanic processes may result in situations where general evacuation strategies are not effective because the risks cannot be adequately assessed in advance. Lateral blasts, debris flows, pyroclastic flows, and surges can move so fast that warning and evacuation are effective only if accomplished well in advance of the actual event. Adequate monitoring and response is essential for public safety. Warning signs, warning systems, and evacuation plans in conjunction with monitoring have been developed for areas around Mount St. Helens and Mount Rainier.

The hazard classification approach seeks to minimize the risk of hazard by locating facilities outside volcanic hazard areas, and by providing emergency evacuation plans for those facilities or risks that cannot be avoided.

The factors to be weighed in developing such as classification and response system include:

- The frequency events such as lahars are likely to be experienced
- The likelihood of early warning and opportunity for evacuation
- The risk to human populations
- The social and economic opportunities that may be lost by a more stringent approach

The method used to estimate the risk of occurrence is to examine historic records. Three different hazard zones are defined in the vicinity of Mount Rainier (Rogers et al. 1996). In that area, Case I debris flows (lahars) are estimated to have an average return interval of 500 and 1,000 years. Case II lahars are estimated to have an average return interval of 100 to 500 years. In the vicinity of Mount Rainier, therefore, the occurrence risk of Case II lahars approaches that of 100-year floods (one-percent chance in any given year). The criteria for avoidance might be considered analogous to that of flood hazard avoidance; however the scientific understanding on which flood frequency is based is much greater than that of volcanic hazards.

The likelihood of early warning varies both according to our scientific knowledge and the degree to which instrumentation to detect early signs of activity are installed and operated. Each volcano has a unique combination of history and hazard conditions. The Pacific Northwest Seismograph Network (PNSN) uses a network of seismic sensors to locate earthquakes in Washington and Oregon. PNSN, in cooperation with the Cascade Volcano Observatory, monitors seismic activity at Mount Rainier, Mount Adams, and Mount St. Helens. If earthquakes are associated with Cascade volcanoes (as recently occurred with Mount St. Helens), the PNSN warns the appropriate agencies. Warnings can also be received by intervals with the NOAA weather radio system.

The effectiveness of evacuations is dependent on the location of a facility and the availability of routes for evacuation that can readily be accessed. An important factor is the capacity of evacuation facilities. If the routes used are limited and the demand is great, congestion will increase the time needed for evacuation. In some cases, accidents could temporarily close evacuation routes or greatly increase evacuation times.

Risk can generally be described in terms of the population affected and the likelihood of effective evacuation within the time period needed. A more heavily populated area generally can be considered at greater risk. Facilities that concentrate human populations such as schools are also considered at greater risk. Facilities that concentrate human populations and contain individuals with limited mobility, such as hospitals or nursing homes, are at an even greater level of risk.

The social and economic opportunities lost by an approach that seeks to limit risk though avoidance include opportunities to build, subdivide or develop land for residential, recreational or commercial purposes.

The avoidance strategy could take two basic forms:

- Identification of uses with a risk exposure judged too great to locate within a volcanic hazard area. This might include a variety of uses with high human exposure.
- Identification of a similar range of uses but with a location criteria based on the ability to effectively evacuate within a short period of time by specific routes and with specific technology that can be relied upon with a great deal of assurance.

The present Lewis County Volcanic Hazard Code excludes all critical facilities from the high volcanic hazard zones. Critical facilities are defined as "facilities for which a significant chance of damage as a result of geological hazard would be too great. Critical facilities include, but are not limited to, schools; hospitals; police, fire and emergency response installations; nursing homes; and installations which produce, use, or store hazardous materials or hazardous waste." The code is more restrictive than some of the more populated valleys around Mount Rainier because it excludes all critical facilities and does not define such facilities by size.

The second approach ties allowed uses to the ability to successfully evacuate. This approach is more costly and time intensive because it requires much more information, infrastructure improvements and site-by site evaluation of risk. This approach requires:

- Upgrading volcano monitoring, warning, and research facilities.
- Determining thresholds for restricting the types of uses to be prohibited versus those allowed with adequate evacuation procedures.
- Establishing evacuation plans on an individual basis and providing a public support system to make those individual plans effective, including regional plans, warning signs, and rehearsed evacuations.
- Transportation upgrades to facilitate evacuations.

Such an approach would require notification to future property owners of risks and requirements by attaching notification of volcanic hazards to property titles and building permits in high-hazard areas. It would also require ongoing public education to ensure that plans remain relevant with changing conditions. Such an approach could be limited to critical facilities or could be applied to any type of development, depending on the degree of risk management desired.

3.7 MINE HAZARD AREAS

Determination of areas where mine hazards are present is based on data of inactive and abandoned mines from Washington DNR. The database and maps rely on annual reports submitted by mining companies since about 1900. Mines abandoned prior to 1900 may not be documented in filed reports. In addition, small and unregistered mines are not documented in the public record. Existing hazard maps may provide a margin of safety against the risks posed by abandoned coal mines.

The primary objective of standards for development within coal mine hazard areas is to reduce risks posed to property and the public. Development standards can provide a margin of safety against the uncertainty of land subsidence by restricting development within areas underlain by abandoned coal mines.

Existing Lewis County regulations in LCC 17.35.930 require an applicant to demonstrate that no hazard to health or safety, persons or property exists at the proposed site as the result of the development. A geotechnical report may be required. The code has no specific standards for the assessment of hazard.

Other approaches that can provide more specificity include:

- Restricting development within coal mine hazard areas can provide a conservative level of protection from subsidence.

- Development within coal mine hazard areas requires standards that consider conditions controlling mine collapse and subsidence.
- Structures can be designed or retrofitted to sustain damage from subsidence while protecting occupants.
- Structure setbacks can be applied to coal mine hazard areas similar to other geological hazards and critical habitats.

The variability of potential hazards warrants a detailed geotechnical investigation of any development overlaying mine workings at a shallow depth. The current code specifies mine hazards as within 50 feet of a mine opening or underlain by workings at a depth of 100 feet or less. The basis of the 100 foot standard is unknown. A depth standard of 200 to 300 feet is used by several Western Washington communities, including Renton, Newcastle and Bellevue, as the threshold for requiring detailed studies. The uncertainty of the potential for coal-mine collapse and land subsidence complicates the assessment of measures to mitigate coal-mine hazards and warrants a conservative approach.

For areas with shallow workings, geotechnical investigation should include a direct subsurface investigation program to investigate potential sinkhole development and trough subsidence. Effects on structures and the potential for damage to roads, utilities and other infrastructure should also be examined.

In risk management, it is appropriate to establish different standards for new subdivision and development on currently undeveloped sites, as opposed to lots that may have existing structures. In the case of new development, the mitigation measure of avoidance should be the first considered through mechanisms such as clustering. In addition, zoning should consider lower density or resource designations for areas with shallow workings.

For areas with deeper workings where sinkholes and large scale subsidence are not a hazard, small-scale subsidence can be a threat to buildings. This can be addressed through building and structure foundations designed for the loads and conditions encountered in the subsidence effects of tilt and strain. The design of utility connections should be flexible to avoid breakage due to tilt and strain.

Site investigation and design standards can minimize damage to public and private infrastructure such as roads and utilities. Design standards for roadway construction can specify flexible materials. Design for drainage can include the maximum predicted subsidence profile to facilitate maintaining positive drainage. Bridges can be designed for an additional factor of safely to accommodate the maximum strains and tilts predicted. Utilities can also be designed for greater factors of safety for tilts and strains and include flexible sections to allow for dislocation. Design measures should provide for maximizing public safety in the case of failure, particularly for gas lines.

3.8 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The existing Lewis County code is generally developed and the geologically hazardous standards are largely founded in science. The following table summarizes some changes that could be made to strengthen the code.

Geologic Hazard Findings and Recommendations	
All Hazard Areas	
Finding	Present code does not stipulate minimum criteria for hazard studies, with the potential for insufficient guidance to staff, inconsistency, and liability for staff decisions if technical studies are not required for sites subsequently damaged
Recommendation	Develop a level of staff expertise sufficient to determine when additional studies are required. This may be accomplished through an on-call services contract with a local consultant. Develop minimum professional standards for analysis and reporting for slope stability studies.
Finding	Tracking of specific conditions placed on private development can be difficult as property changes hands. New owners may not be aware of risk or conditions.
Recommendation	Attach critical area and buffer conditions to: • Subdivisions through restrictions designated on the face of the plat with specific conditions on alteration and use (often referred to as Native Growth Protection Easements (NGPEs)); • On building permits through conditions that are filed as notice on titles. Require technical studies, including designation of geographic areas of hazard to be provided to the county in a manner that can be easily tracked through the GIS system. Investigate use of GPS as an alternative to cadastral survey to reduce cost to landowners.
Landslide Hazard Areas	
Finding	Landslide hazards are varied and pervasive throughout the county. The basic landslide guidelines for percent slope and from geologic studies provide general guidance as to risk exposure but do not identify all hazard areas
Options	Add to existing designation of areas of landslide risk. • Slopes greater than 40 percent with a vertical relief of ten or more feet. This criteria is partially addressed for the Centralia-Chehalis Area in the Allen J. Fiksdal study referenced, but is not generally provided for in the rest of the County. • Areas at risk from snow avalanches. • Areas designated with soils as having a “severe” limitation for building site development. • Slopes in the nearby foothills show landslide hazards perpendicular to planes of weakness, as well as parallel • Unconsolidated deposits around lakes, especially delta deposits (primarily for seismic hazard). Employ DNR model (Montgomery) to obtain multi-variable assessment
Finding	The landslide hazard areas do not distinguish levels or risk.
Options	Distinguish between moderate and high hazard areas, generally allowing greater flexibility in areas with lower hazards.

Geologic Hazard Findings and Recommendations	
Landslide Hazard Areas (continued)	
Finding	The guidelines for identifying risk exposure do not accurately characterize risk on a site-by site basis.
Options	• Keep existing code – will result in a high level of liability • Provide a protective approach with a no-alternation standard for areas of potential risk, including buffers. Provide potential for alternation of the no-alteration standard based on site-specific study by a qualified professional.
Finding	Landowners are likely to be unfamiliar with the presence or risk of landslide or erosion hazards and are likely to undertake activities not under county permit review, such as vegetation removal, or negative stormwater management activities, that will increase risks
Recommendation	• Provide handouts and other information at the Permit Center • Develop a referral list of qualified professionals • Provide some level of qualified advice/assistance at no charge through permit function
Finding	The existing code does not provide clear standards for acceptable risk in defining whether a landslide hazard exists.
Recommendation	Provide additional specific guidance on acceptable standards for risk of failure to be used by a qualified professional in establishing that a landslide hazard is not present on sites.
Findings	The existing code does not provide specific buffer dimensions or specific standards for establishing buffer dimensions.
Options	• Keep existing code lacking specific standard, with current administration – will result in possible inconsistency in whether buffers are required and the criteria for buffers, a high level of liability is inherent in this approach, or • Keep existing code lacking specific standard, with augmentation of staff with qualified geologist - will result in more consistency in whether buffers are required and the criteria for buffers, a moderate level of liability is inherent in this approach, the additional cost is relatively high, additional studies by qualified professionals will be needed for specific sites, or • Provide specific buffers from the top and other edges of landslide-prone slopes and run-out zones and add provisions for optional site specific studies by a qualified professional standards for variation of those standards – will result in low to moderate liability, slight additional staff expense
Finding	Vegetation management is essential for mitigating landslide hazard potential.
Options	Include provisions to require retention of native vegetation on steep slopes to improve stability (also consider fire safety and other issues)
Finding	Stormwater management is essential for mitigating landslide hazard potential.
Options	Include provisions to require stormwater management plans on steep slopes to maintain stability.

Geologic Hazard Findings and Recommendations	
Erosion Hazards	
Finding	Erosion hazards are present on sites that are not also a landslide hazard, however the present code provides standards that are the same for both.
Options	Add a separate erosion hazard designation and regulations to address erosion hazard separate from landslide hazards.
Findings	Existing code regulates only severe erosion hazard soils. Bare soil conditions for development, even without severe hazard soils present risk or erosion/sedimentation.
Options	Identify range of hazard conditions and provide sliding scale of erosion control BMPs based on range of hazard.
Finding	Erosion hazards are greater where surface water is in proximity to sites. The current code extends stream buffers to slopes of 50 percent or greater but does not provide protection from erosion on less steep slopes that can have a substantial erosion rates.
Options	Provide for erosion hazard based on proximity to receiving waters through: • Applying buffers to slopes less than 50% • Providing erosion control standards based on proximity to receiving waters.
Finding	Vegetation management is essential for mitigating erosion hazard potential.
Options	Include provisions to require retention of native vegetation on steep slopes to reduce erosion (also consider fire safety and other issues)
Finding	Stormwater management is essential for mitigating erosion hazard potential.
Options	Include provisions to require stormwater management plans on steep slopes to improve stability.
Alluvial Fan Hazards	
Finding	Floods and catastrophic debris flows can be generated from steep confined channels and deposited on alluvial fans. • County currently has no pre-identification of alluvial fans in GIS. • Information on existence of risk is not readily available to permit processors or applicants
Options	• Retain existing identification in the code with no supporting information - will result in inconsistency in application and a high level of liability • Identify existing alluvial fans on an informal basis for use by county staff in administration - - – will result in a somewhat lower inconsistency in application and a moderate to high level of liability • Contract with a qualified geologist to identify potential alluvial fan hazards with Lidar system and add to GIS mapping for administration
Hazard Identification	Assessing risk associated with active portions of alluvial fans is sometimes difficult. Basing this assessment on recent deposition (past 20 to 100 years) may not provide adequate protection. The character and risks associated with the hazard are likely to change over time.

Options	• Continue existing code administration
	• After identification of hazard areas, consider all alluvial fan areas active unless analysis of fan topography, stratigraphy, and watersheds demonstrates otherwise.
	  o Restrict new building unless specific studies and management plans are adopted.
	  o Allow development only where management plans are implemented for the entire alluvial fan area, rather than on a case-by case basis.

<table>
<tr><th colspan="2">Geologic Hazard Findings and Recommendations</th></tr>
<tr><td colspan="2">Alluvial Fan Hazards (continued)</td></tr>
<tr><td>Finding</td><td>Alluvial fan hazards can reasonably be regulated either as a geological hazard or a flood hazard</td></tr>
<tr><td>Options</td><td>Regulate only as a geological hazard
Regulate only as a flood hazard
Provide consistent regulations in both sections. The regulations as a geological hazard would apply to those areas without a management plan, the flood regulations would primarily apply after adoption of a management plan</td></tr>
<tr><td>Finding</td><td>Some alluvial fans have already been built on, but implementation of a management plan to reduce risk to an acceptable level may not be practical</td></tr>
<tr><td></td><td>Consider buyouts of particularly vulnerable residences as part of individual management plans.</td></tr>
<tr><td colspan="2">Channel Migration Hazards</td></tr>
<tr><td>Finding</td><td>Failure to recognize the dynamic nature of river and stream systems can lead to damage to public and private facilities. Limited designation of channel migration zones has occurred on the upper Cowlitz and the Cispus.</td></tr>
<tr><td>Options</td><td>Do not regulate as present, or
Regulate as either a:
Geological hazard;
Flood area;
As part of Aquatic Habitat progection
Any combination of the above Critical Areas</td></tr>
<tr><td>Finding</td><td>Channel migration zones are identified for only a portion of the county</td></tr>
<tr><td>Options</td><td>Regulate only the areas currently studied, or
Invest in additional studies to create a channel migration hazard map for all major streams with areas of higher intensity zoning the first priority</td></tr>
<tr><td colspan="2">Seismic Hazards</td></tr>
<tr><td>Finding</td><td>Seismic hazards are present throughout the County, with higher risk areas associated with certain substrate materials, slope position near landslide-prone areas, and shorelines. Standards such as the building code do not address avoidance options.</td></tr>
<tr><td>Options</td><td>Continue to use uniform building code standards (or the International Building Code) or,
Create a more integrated seismic risk management system including:
Identify and map additional hazard areas based on alluvial deposits or organic layers and classify seismic hazard areas as high, moderate, and low risk zones and relate to allowed uses.
Add avoidance or additional study requirements for higher risk areas that may include:
➢ Avoidance of highest risk areas
➢ Geotechnical analysis of high risk specific sites and plans.
Base the building standards on the classification of the structure and risk to occupants (e.g., residence, barn, critical structure).
Add specific standards for areas prone to liquefaction.
Add a new category of seismic landslide hazards associated with lakes to identify high, moderate, and low risk zones. Implement an avoidance standard where appropriate.</td></tr>
</table>

Geologic Hazard Findings and Recommendations	
Volcanic Hazard Areas	
Finding	Volcanic hazards in Lewis County include areas near Mount Rainier as well as the downstream valleys of Mount Rainier and Mount Adams.
Options	• Maintain current approach of prohibiting critical facilities and develop a more specific definition of critical structures. • Consider a classification system for hazards together with a sliding scale or restrictions based on hazard and evacuation potential. Under either approach, as a non-regulatory action: • Update volcanic hazard areas based in current studies. • Upgrade monitoring and warning systems and criteria for evacuation.
Mining Hazards	
Finding	Existing code defines a hazards as within 50 feet of a mine opening or underlain by workings at a depth of 100 feet or less. The basis of the 100 foot standard is unknown. Rock strength controls the depth at which mine collapse will transmit to the surface as well as the surface area affected by mine collapse and subsidence. The minimum area of subsidence is determined by the area of roof collapse plus an additional area determined by the internal friction angle of the rock.
Options	• Continue to utilize the existing 100 foot depth standard, if documentation can be identified that provides justification based on rock strength. • Increase the depth standard to 200 to 300 feet to provide a higher threshold of risk reduction; • Provide a setback area based on the angle of potential transmittal, or a uniform 100 foot setback to reduce effort in estimating rock strength and to provide a margin of safety as well as account for potential error in survey of underground workings.
Finding	Existing Lewis County regulations in LCC 17.35.930 require an applicant to demonstrate that no hazard to health or safety, persons or property exists at the proposed site as the result of the development. A geotechnical report may be required. The code has no specific standards for the assessment of hazard.

Options	• Retain existing code general criteria
	• Develop additional standards for more conservative protection of life and property, including
	  • A no development standard for areas with shallow workings, in the absence of geotechnical investigation
	  • For shallow workings, geotechnical standards may include a direct subsurface investigation program to investigate potential sinkhole development and trough subsidence. Effects on structures and the potential for damage to roads, utilities and other infrastructure should also be examined.
	• Establish a higher avoidance standard for new subdivision and development on currently undeveloped sites. In addition, zoning should consider lower density or resource designations for areas with shallow workings.
	• For areas with deeper workings small-scale subsidence can be addressed through building and structure foundations designed for the loads and conditions encountered.
	• Develop site investigation and design standards for public and private infrastructure such as roads and utilities.

4. GEOLOGICALLY HAZARDOUS AREAS REFERENCES

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